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Technical Bulletin No. 1891

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Issued December 2000

The North Dakota Grasshopper Integrated Pest Management Demonstration Project

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Abstract

The North Dakota Grasshopper Integrated Pest Management (GHIPM) Demonstration Project was established from 1987 to 1993 in western North Dakota and eastern Montana. The objectives of the project were: (1) to manage grasshopper populations in the study area, (2) to compare the effectiveness of an integrated pest management (IPM) program for rangeland grasshoppers with the effectiveness of a standard chemical control program on a regional scale, (3) to determine the effectiveness of early sampling in detecting incipient grasshopper infestations, (4) to quantify short- and long-term responses of grasshopper populations to treatments, and (5) to develop and evaluate new grasshopper suppression techniques that have minimum effects on nontarget species.

Three adjacent blocks of rangeland were used for the project. The 3,431-km^2 (847,815-acre) demonstration block was managed with available IPM techniques, such as conducting intensive grasshopper surveys to define more accurately areas of infestation, using *Nosema locustae* baits and insecticidal baits, treating small areas of infestation ("hot spots") to prevent larger outbreaks, increasing the swath width of aerial applications of insecticidal baits, and by optimally timing treatments. An adjacent 5,294-km^2 (1,308,171-acre) standard block was managed with conventional chemical control techniques. In this block, large areas exceeding 4,047 ha or 10,000 acres were treated with carbaryl sprays. A 4,373-km^2 (1,080,588-acre) untreated control block was established in an adjacent section in eastern Montana.

The effectiveness of IPM in managing grasshopper populations on a regional scale was evaluated by comparing grasshopper populations and control method data in the two treatment blocks in North Dakota (i.e., the demonstration block and the standard block). Specifically, the following variables were examined: (1) number of sampling sites in the adult and nymphal surveys, (2) area treated, (3) cost of treatment, (4) amount of insecticide applied, (5) densities of grasshoppers, and (6) frequency distribution of grasshoppers.

The effectiveness of treatments in the demonstration block was evaluated by conducting grasshopper population surveys before and after treatments. Treatments included (1) aerial application of 2.5×10^9 spores of *Nosema locustae* on wheat bran per hectare (1×10^9 spores/acre); (2) aerial application of 2-percent carbaryl–bran bait applied at a rate of 1.68 kg/ha (1.5 lb/acre); (3) aerial application of malathion sprays applied as 585 mL of Malathion-ULV® per hectare (8 fluid oz/acre); (4) aerial application of carbaryl sprays at 1.46 L/ha (20 oz/acre) of a 4:1 Sevin-4-oil® and diesel mix per hectare (8 oz active ingredient [AI] per acre); (5) ground application of 2-percent carbaryl–bran bait applied at a rate of 2.24 kg/ha (2.0 lb/acre); and (6) aerial application of 2-percent carbaryl–bran bait at 1.68 kg/ha (1.5 lb/acre) over an extended swath width.

Approximately twice as many sections (i.e., 640-acre blocks) of rangeland were sampled in the demonstration block as in the standard block. From 1987 to 1993, 62,214 ha (153,734 acres) were treated in the demonstration block, while 121,110 ha (299,268 acres) were treated in the standard block. Most treated areas in the demonstration block were smaller than 1,000 ha (2,471 acres); most treated areas in the standard block were larger than 13,000 ha (32,124 acres). The total amount of insecticide active ingredient (i.e., of carbaryl and malathion) applied to rangeland from 1987 through 1993 was at least 2.5 times greater in the standard block than in the demonstration block. Total treatment costs were 65 percent greater in the standard block than in the demonstration block.

Grasshopper populations were generally similar in the demonstration and standard blocks. Grasshopper densities were significantly greater in the standard block than in the demonstration block in 1987 and 1992 but not in 1988 through 1991 or in 1993. The standard block seemed to support larger grasshopper infestations than the demonstration block, particularly in 1987, 1990, and 1992.

Sixty-five species of grasshoppers were collected from 393 evaluation sites within the demonstration block on the pretreatment sampling dates from 1987 through 1993. *Melanoplus sanguinipes* and *M. infantilis* were the two most abundant species, constituting, respectively, 16.4 and 15.4 percent of all grasshoppers collected. Forty-six species were relatively rare, constituting less than 1 percent of the total collected.

A 3-year study of the effect of *Nosema*–bran bait on grasshoppers suggested that the microbial insecticide had little, if any, effect on grasshoppers either immediately after treatment or in subsequent years.

Aerial and ground applications of malathion and carbaryl sprays were the most efficacious treatments. Immediate reductions in the total number of grasshoppers at the nine blocks treated with these insecticides ranged from 84 to 99 percent.

The effects of carbaryl–bran bait on grasshoppers were assessed at 22 evaluation sites in 3 aerial-application and 6 ground-application experiments. Total populations of grasshoppers were reduced by an average of 44.5 percent at the evaluation sites in the treated areas but declined by an average of only 3.3 percent at 18 untreated control sites. Ground and aerial applications had similar short-term effects on populations of total grasshoppers. The moderate levels of control from carbaryl–bran baits were caused, in part, by the species composition of grasshoppers. The percent reduction in total grasshoppers was negatively correlated ($r = -0.41$) with the percentage of bran-rejecting species in the treated areas.

The treatment of small areas of infestation, or hot spots, with ground applications of malathion sprays or carbaryl–bran baits was effective in suppressing grasshopper populations. Two applications of carbaryl–bran bait were needed to control grasshoppers in some cases, particularly when initial densities were very high.

Eighteen field experiments compared grasshopper populations in treated sites and untreated control sites (excluding the *Nosema*-bran bait experiment) a year after treatment. Overall, populations at treatment evaluation sites declined by an average of 53.2 percent a year after treatment. In contrast, densities at untreated control sites increased by an average of 33.6 percent a year after treatment. The data suggest that, in general, treatments were effective in suppressing second-year populations of grasshoppers.

We conclude that increased sampling to delineate more exactly the area of grasshopper infestation, carefully timed treatment applications, and the use of hot-spot treatments with ground applications of either insecticidal sprays or baits should be incorporated into grasshopper IPM programs as alternatives to large-scale aerial applications of insecticidal sprays. Results from the North Dakota GHIPM Demonstration Project indicate that adopting these more intensive management methods will greatly reduce both the cost of grasshopper control treatments and the amount of insecticide applied to rangeland.

Introduction

Grasshoppers are a significant component of grassland ecosystems in the Western United States. They are an important food source for many vertebrate species (Wiens and Rotenberry 1979, McEwen 1987, Kaspari and Joern 1993), contribute to nutrient and energy cycling (van Hook 1971, Mitchell and Pfadt 1974, Hewitt 1977, Rodell 1977), feed on noxious plants (Lockwood 1993), and contribute to overall biodiversity of grasslands (Rees 1973, Quinn et al. 1993, 1995). These benefits of grasshoppers, however, are often overshadowed by their destruction of valuable forage during periods of outbreaks. Hewitt (1977) estimated that an average density of 1 grasshopper/m^2 can destroy 13–17 kg of forage per hectare of rangeland. During grasshopper outbreaks, the total forage destroyed by these insects can be substantial. The monetary loss is sometimes quite high. An estimated $393 million was lost to grasshoppers in the Western United States in 1977 alone, when 563,324 ha (1,391,998 acres) of rangeland were treated (Hewitt and Onsager 1983).

Because grasshopper infestations on rangeland are often widespread, their treatment requires the cooperation of private individuals and State and Federal agencies. The U.S. Department of Agriculture (USDA), Animal and Plant Health Inspection Service (APHIS) is responsible for coordinating grasshopper control programs by conducting surveys, establishing control tactics, monitoring populations, and developing methods for grasshopper suppression (USDA 1987). From 1972 through 1995, approximately 18,897,342 ha (46,696,162 acres) of rangeland were treated under APHIS' grasshopper and Mormon cricket control programs in the Western United States (table 1). The largest control effort occurred in 1985, when 5,299,781 ha (13,095,992 acres) were treated with the broad-spectrum insecticides malathion and carbaryl. Malathion and carbaryl sprays are generally applied at rates of 0.65 and 0.56 kg AI per hectare, respectively (0.58 and 0.50 lb AI per acre, respectively). Thus, in 1985 alone, more than 2,900,000 kg of the active ingredients in these compounds were applied to rangeland.

A standard grasshopper control program involves treating large (i.e., >10,000 acres or 4,047 ha) grasshopper infestations with aerial applications of either carbaryl, malathion, or acephate sprays. The emphasis is typically placed on control after outbreaks occur. Because of the cost and general environmental and health problems associated with large-scale applications of insecticides, APHIS proposed that integrated pest management (IPM) techniques be developed and used to keep rangeland grasshoppers below economically damaging levels as an alternative to standard grasshopper control programs (USDA 1987).

In 1987, the North Dakota Grasshopper Integrated Pest Management (GHIPM) Demonstration Project was established as part of the overall APHIS-directed multiagency GHIPM Project to study the feasibility of using IPM for managing grasshoppers. The major objectives of the Demonstration Project were (1) to manage grasshopper populations in the study area, (2) to compare the effectiveness of an IPM program for rangeland grasshoppers with a standard chemical control program at a regional scale, (3) to determine the effectiveness of early sampling in detecting incipient infestations, (4) to quantify short- and long-term responses of grasshopper populations to treatments, and (5) to develop and evaluate new grasshopper suppression techniques that have minimum effects on nontarget species (USDA 1987). Operationally, these new management tactics included conducting intensive grasshopper surveys, using the entomocidal protozoan *Nosema locustae* and insecticidal baits, treating small hot spots to prevent larger infestations, and increasing the swath width of aerial applications of insecticidal baits.

Materials and Methods

Study Area

The North Dakota GHIPM Demonstration Project involved treating two adjacent blocks of rangeland in the Little Missouri National Grassland in Western North Dakota (fig. 1). The Little Missouri National Grassland is administered by the USDA Forest Service. The IPM demonstration block was managed using available IPM techniques. This block consisted of 3,431 km^2 (847,815 acres) of grassland within the Little Missouri National Grassland McKenzie District (fig. 2, table 2). The McKenzie District has three separate sections, the north section adjacent to Lake Sakakawea; a small middle section adjacent to Fort Berthold Indian Reservation, northeast of Watford City, ND; and a south section adjacent to the Montana border and surrounding the north unit of Theodore Roosevelt National Park.

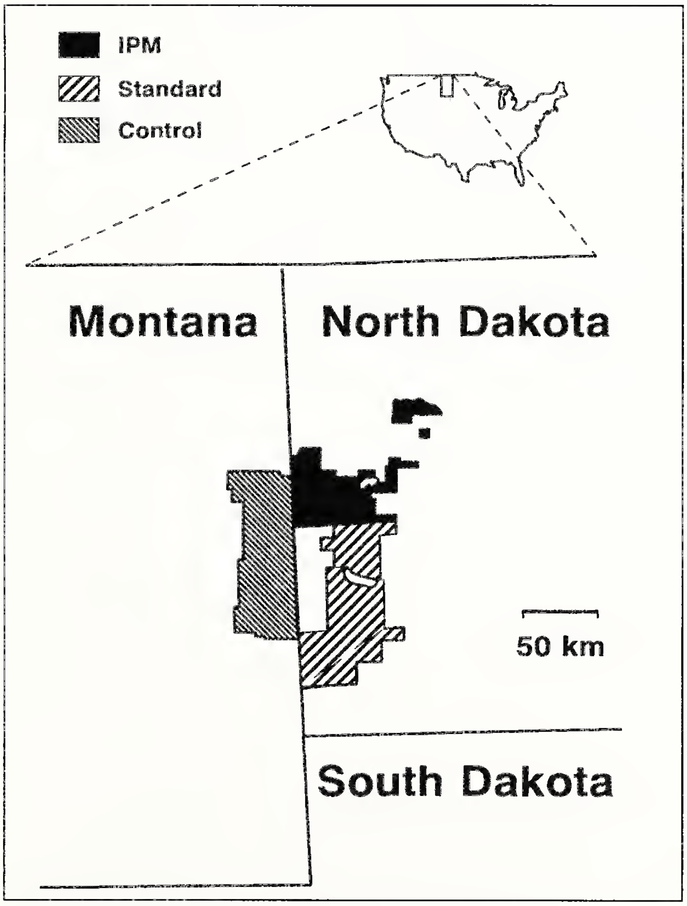

Figure 1—Location of the IPM demonstration, standard, and control blocks in the northern Great Plains Region of the United States. The southern section of the standard block was also included in treatment programs in 1993.

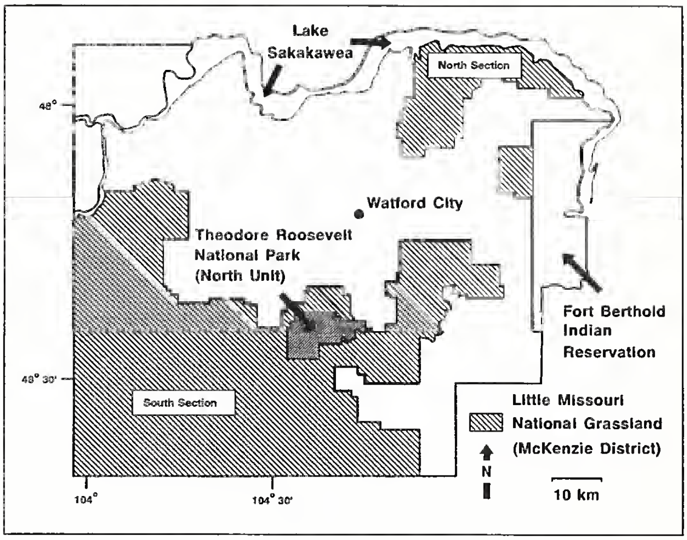

Figure 2—IPM demonstration block within the McKenzie District of the Little Missouri National Grassland, North Dakota

A second block, the standard block, was managed with conventional chemical control techniques. This block consisted of 5,294 km^2 (1,308,171 acres) of grassland within the Little Missouri National Grassland Medora District, located in Golden Valley, Slope, and Billings Counties of North Dakota (table 2, fig. 3). The Medora District surrounds the south unit of Theodore Roosevelt National Park. A 4,373-km^2 (1,080,588-acre) untreated control block was established in Wibaux, Dawson, and Richland Counties in Montana, directly west of the demonstration and standard blocks. This block was not involved in a Federal grasshopper suppression program.

The project was located in a part of the northern Great Plains region that can be classified as a northern mixed-grass prairie because of its mixtures of short-grasses and tall-grasses (Risser et al. 1981). Dominant tall-grasses in the region are *Agropyron smithii* (western wheatgrass), *A. cristatum* (crested wheatgrass), and *Stipa* spp. (needle grasses). Short-grasses are predominantly *Bouteloua gracilis* (blue grama grass) and *Buchloe dactyloides* (buffalo grass). Soils in the region are generally entisols, or mineral soils that lack significant soil layers.

Average annual precipitation and temperature in the region are approximately 380 mm (15 in) and 5.1 °C (41.2 °F), respectively. Aboveground net primary

production of the region is approximately 224 g/m^2/year (Lauenroth 1979).

Population Surveys

Grasshopper nymph populations in the demonstration, standard, and control blocks were monitored in early June of each year from 1987 through 1993 by APHIS–Plant Protection and Quarantine (PPQ) personnel to identify general areas of infestation (table 2). Grasshopper populations in the demonstration and standard blocks were typically surveyed along roads or established trails at 1.6- to 3.2-km intervals and 4.8- to 8.0-km intervals, respectively. Sampling was done at least 30 m from roads or 15 m from trails. In areas of relatively high grasshopper densities, sampling was often done at smaller intervals. In the control block, grasshopper populations were sampled less intensively; grasshopper densities in this block were typically at intervals of approximately 10 km along roads.

At each site within the demonstration and standard blocks, grasshoppers were collected in 40 180-degree sweeps of a standard 40.6-cm (16-in)-diameter sweep net. The number of grasshoppers collected in 40 samples divided by 10 was used as an estimate of number of grasshoppers per m^2 (Records 1977). Areas of rangeland with relatively high grasshopper populations were sampled more intensively than other areas. Also, more sites were sampled if previous surveys indicated high grasshopper densities. Populations of grasshoppers in the control block were monitored differently. At each site within the block, an estimator walked along a randomly chosen transect and counted the number of grasshoppers in 18 "visually determined" 1-ft^2 (i.e., 0.093-m^2) areas. The total number of grasshoppers in the 18 plots divided by 2 was used as an estimate of the number of grasshoppers per m^2 for each site (USDA–APHIS–PPQ 1985 unpubl.).

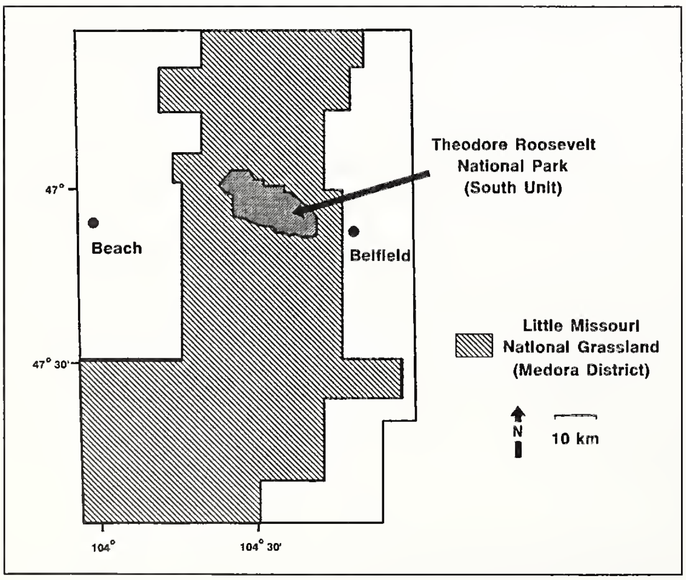

Figure 3—Standard block within the Medora District of the Little Missouri National Grassland, North Dakota.

In the demonstration and standard blocks, based on the results of the nymphal surveys, delineating surveys were conducted to determine specific sites that required treatment (table 2). In the standard block, general grasshopper surveys were conducted after treatment. In the demonstration block, grasshopper densities and species composition were estimated in treatment areas before and after treatments as part of the detailed study to develop and evaluate IPM techniques (see below). Final adult grasshopper surveys were conducted in all areas during August of each year from 1987 through 1993 to predict the next year's infestations.

Grasshopper Management Options

In the standard block, grasshopper populations were managed under APHIS' longrange cooperative program, similar to the chemical control alternative described in the final environmental impact statement for the Rangeland Grasshopper Cooperative Management Program (USDA 1987). To initiate control programs within the standard block, several criteria had to be met. First, grasshopper infestations had to exceed 4,047 ha (10,000 acres) in one location (table 2). The size and severity of infestations were determined from adult grasshopper surveys conducted by APHIS in the year before treatments and from nymph surveys conducted during the treatment year. This information was given to Federal and State agencies involved in rangeland management (e.g., the USDA Forest Service, the U.S. Department of the Interior's Bureau of Land Management), as well as to local ranchers and grazing associations. Second, APHIS had to receive a request for help in treating grasshopper infestations from the Government agencies or ranchers. Third, treatment of the area

had to be economically and logistically feasible. Areas smaller than 4,047 ha (10,000 acres) could be treated but only if the infestations were considered incipient and had a high potential to expand and threaten the surrounding areas. Insecticidal sprays are used in typical control programs. These were the same criteria APHIS used to institute treatment programs on all rangeland in the Western United States.

In the demonstration block, grasshopper populations were managed with several available IPM techniques, as described by the preferred alternative grasshopper management tactics outlined in the final environmental impact statement for the Rangeland Grasshopper Cooperative Management Program (USDA 1987). These techniques included (1) providing more detailed surveys of grasshopper populations so that small areas of infestations could be defined; (2) treating small areas of grasshopper infestations ("hot spots") rather than just the minimum 4,047 ha (10,000 acres) of infestation required under the standard grasshopper control program; and (3) using control methods other than the conventional large-scale aerial applications of insecticidal sprays. All grasshopper infestations in the demonstration block, regardless of size, were treated (table 2).

The control block was not involved in a large-scale grasshopper control program. Although individual landowners in the control block occasionally treated grasshoppers, the amount of rangeland treated in this block was relatively small.

Four different formulations of insecticides and six different application methods were used in the North Dakota GHIPM Demonstration Project from 1987 to 1993 (table 3): (1) standard aerial application of carbaryl sprays, (2) standard aerial application of 2-percent carbaryl–bran bait applied with a standard 13.7-m swath width, (3) standard aerial application of 2-percent carbaryl–bran bait applied with an extended 27.4-m swath width, (4) standard aerial application of malathion spray, (5) ground application of 2-percent carbaryl–bran bait, and (6) aerial application of *Nosema*–bran bait. These methods represented most of the control tactics that were available for managing grasshoppers.

In the demonstration block, all six control methods were used. In the standard block, only two methods were used: carbaryl sprays were used predominantly, but 95 ha (235 acres) in this block were treated with carbaryl bait. Treatments in the IPM demonstration block were applied to suppress grasshopper populations and to evaluate new control methods, whereas treatments in the standard block were made only to control grasshopper infestations.

The specific treatments and areas of treatment within the demonstration block were chosen on the basis of data from initial grasshopper surveys and were prescribed in cooperation with the APHIS and Agricultural Research Service project entomologists, the local APHIS PPQ Officer-in-charge (OIC), and the GHIPM Project Director. Treatments within the standard block were prescribed in cooperation with the APHIS OIC, land managing agencies, and local ranchers. The decision to use specific treatments was based on grasshopper densities, size of infestation, species composition of grasshoppers, age structure of grasshopper populations, proximity to sensitive areas (e.g., water), the predicted efficacy of the treatment, amount of vegetation cover, terrain, and weather conditions.

The standard malathion and carbaryl spray treatments are most often used as corrective treatments to control large infestations quickly. Malathion has a relatively short period of residual activity (2–5 days), so it is generally selected for use later in the season, when most grasshoppers have already hatched (Foster and Onsager 1995b). Also, malathion is used optimally during warm and dry conditions. Carbaryl has a longer period of residual activity (14–21 days) than malathion and can also be used over a broader range of climatic conditions (Foster and Onsager 1995b). Carbaryl performs well at temperatures from 15.6 to 26.7 °C (60 to 80 °F). The Sevin-4-oil formulation of carbaryl is relatively resistant to removal by rainfall after the spray has dried on the vegetation. The insecticidal sprays were generally used in the demonstration block to control moderate to large grasshopper infestations (1,347–15,022 ha, mean of 5,894 ha [3,328–37,120 acres, mean of 14,564 acres]) from early July to early August.

Nosema–bran bait was used for experimental purposes to control a grasshopper infestation in a large sharp-tailed grouse management area. Standard aerial applications of carbaryl–bran bait were used to treated moderately large grasshopper infestations (731–2,550 ha, mean of 1,782 ha [1,806–6,301 acres, mean of 4,403 acres]). *Nosema*– and carbaryl–bran baits were applied to relatively younger grasshopper populations, from mid-June to early July.

Hot-spot treatments with aerial applications of malathion were made to infestations ranging from 129 to 366 ha (135 to 904 acres). Smaller infestations (10–85 ha [25–210 acres]) were treated by ground applications of carbaryl–bran bait. Some of these infestations required two applications.

Aerial applications of malathion and carbaryl were generally made with 585 mL/ha (8 fluid oz/acre) of Malathion-ULV concentrate (0.65 kg AI/ha) and 1.46 L/ha (20 fluid oz/acre) of diesel-diluted Sevin-4-oil (0.56 kg AI/ha), respectively. Carbaryl–bran bait was applied aerially with aircraft equipped with a standard bait spreader, modified as described by Foster and Roland (1986). Generally, 2-percent carbaryl wheat bran was used at a rate of 1.68 kg/ha (1.5 lb/acre) (0.03 kg AI/ha). Ground applications of carbaryl–bran bait were made with bait spreaders mounted to either a truck or an all-terrain vehicle. Baits containing 2-percent carbaryl were generally ground-applied at a rate of 2.24 kg/ha (2.0 lb/acre) (0.04 kg AI/ha). Technical aspects of aerial and ground applications of insecticidal sprays and baits are discussed by Foster and Onsager (1995a,b), Foster and Reuter (1995), Huddleston et al. (1995) and Boetel et al. (1995).

Methods for Evaluating the GHIPM Project

The effectiveness of IPM in managing grasshopper populations on a regional scale was evaluated in the North Dakota GHIPM demonstration project by comparing the IPM program in the demonstration block with the conventional treatment program in the standard block. Specific variables used in the evaluation included number of sites and sections of rangeland included in the adult and nymphal surveys, area treated, cost of treatment, amount of insecticide applied, densities of grasshoppers, and frequency distributions of grasshoppers.

The Kruskal–Wallis test (Sokal and Rohlf 1981) was used to compare mean grasshopper densities in the standard and demonstration blocks in each year. The SAS procedure NPAR1WAY was used for the statistical analysis (SAS Institute 1985). A G-test for independence was used to determine if the frequency distributions of grasshopper densities in the demonstration and standard blocks were different. Statistical comparisons were not made between the two treated blocks and the control block because grasshoppers were sampled differently in the control block. Because of the specific tactics and timeliness of the treatments employed, the cost and amount of insecticide applied to rangeland were expected to be less in the IPM demonstration block than in the standard block; however, grasshopper densities in the two blocks were expected to be similar.

Methods for Evaluating Specific Treatments in the Demonstration Block

In each field study within the demonstration block, densities of all grasshopper species were estimated at evaluation sites using the ring-count method (Onsager and Henry 1977), as modified by Foster and Reuter (1995). Grasshoppers were counted in 40 0.1-m^2 rings placed approximately 5 m apart in a 64-m-diameter circle. Relative abundances of each species and instar or stage were determined by collecting grasshoppers near the circle of rings with 400 sweeps (200 high and 200 low) of a standard sweep net. Densities of individual grasshopper species were estimated by multiplying the relative abundance of a particular species by total grasshopper density. Grasshopper densities typically were estimated 24 hours before treatment, weekly after treatments until the end of the season, and the following year.

Within the demonstration block, replicating treatments was not possible because entire areas of grasshopper infestations were included in the treatment program and the treatment areas were often too large to replicate outside the demonstration block. Generally, grasshopper populations were monitored at several systematically placed evaluation sites within the treated areas, and

these populations were compared with populations at several control evaluation sites outside of the treatment area. Evaluation sites were chosen without prior knowledge of species composition of grasshoppers or vegetation. Because of the pseudoreplicated treatment sites (Hurlbert 1984), it was not possible to separate statistically treatment and location effects. A qualitative assessment of treatment effects was made by comparing densities of grasshoppers at the treatment and control sites before and after treatments.

Response variables measured in each field study included densities of total grasshoppers, densities of each dominant species, and percentage of change in densities of grasshoppers between pretreatment and posttreatment sampling dates. Dominant grasshoppers were defined arbitrarily as species that constituted at least 10 percent of all individuals collected on the pretreatment sampling dates. Changes in grasshopper populations were estimated by comparing pretreatment densities of grasshoppers with immediate posttreatment densities, average posttreatment densities during July of the treatment year, and average posttreatment densities during June and July of subsequent years.

Additional response variables estimated in the studies involving bran baits were densities of bran-rejecting species, bran-accepting species, and bran-vulnerable species, and percentage changes in densities among these three groups. The degree of acceptance of bran baits was defined according to Onsager et al. (1995). Bran-accepting grasshoppers included *Melanoplus* spp., *Ageneotettix deorum* (Scudder), *Aulocara elliotti* Thomas, *Camnula pellucida* Scudder, *Hadrotettix trifasciatus* (Say), *Spharagemon equale* (Say), *Stenobothrus brunneus* Thomas, and *Mermiria bivittata* (Serville). Bran-rejecting species included *Aeropedellus clavatus* (Thomas), *Amphitornus coloradus* (Thomas), *Cordillacris crenulata* (Bruner), *C. occipitalis* (Thomas), *Hesperotettix viridis* (Scudder), *Metator pardalinus* (Saussure), *Phlibostroma quadrimaculatum* (Thomas), and *Trachyrhachys kiowa* (Thomas). Bran-vulnerable species are *Aulocara femoratum* (Scudder), *Eritettix simplex* (Scudder), *Melanoplus femurrubrum* (DeGeer), *Opeia obscura* (Thomas), *Phoetaliotes nebrascensis* (Thomas), and *Psoloessa delicatula* Scudder.

Late-hatching grasshopper species were excluded from the estimates of the average posttreatment densities during July because these species did not occur at the time of treatments. These species included *Xanthippus corallipes* Haldeman, *Arphia conspersa* Scudder, *Chortophaga viridifasciata* (DeGeer), *E. simplex*, and *P. delicatula*. *E. simplex* and *P. delicatula* constituted a relatively high proportion of the total grasshopper population during late July and August.

Analysis of variance was used to compare pretreatment grasshopper densities at the treatment and control evaluation sites. Repeated-measures analysis of variance (Moser et al. 1990, Potvin et al. 1990) of total grasshopper densities was used to determine whether grasshopper densities changed over time. Statistical contrasts were made between average posttreatment densities during July of each year of the study with pretreatment densities. Response variables were either square root or $\log_{10}$ transformed to ensure normality and homoscedasticity of residuals. Fisher's protected least significant difference test was used for mean comparisons. The SAS procedure PROC GLM was used for the analyses (SAS Institute 1985).

***Nosema*–Bran Bait Study Methods.**—

Tobacco Garden.—*Nosema*–bran bait was used in a single field experiment to treat the 10,724-ha Tobacco Garden block. The Tobacco Garden block was located in the north section of the demonstration block, adjacent to Lake Sakakawea (fig. 4). The *Nosema locustae* bait treatment was chosen for this field study to evaluate the efficacy of this microbial control method and because the grasshopper infestation was located in a sharp-tailed grouse management area.

The Tobacco Garden block was treated with 1.12 kg of *Nosema*–bran bait per hectare from June 22 to June 26, 1987. The *Nosema* bait, NOLO BAIT® (Evans BioControl, Inc., Durango, CO), was formulated by applying 2.2×10^9 spores of *N. locustae* to 1 kg of flaky wheat bran. The bait treatment was applied aerially with an Ayers Bull Thrush SR2 aircraft with a modified standard bait spreader (Foster and Roland 1986) operating from an altitude of 15 to 30 m at 193 km/hour. Swath widths were approximately 30 m. There was no precipitation during or immediately after treatments.

Before treatment, 21 evaluation sites were selected within the Tobacco Garden block to monitor grasshopper populations. Sites were approximately 3.2 km apart, located near the center of alternate 259-ha (640-acre) sections. An additional three untreated control sites were located outside of the block. These sites were more than 8 km from the block and more than 16 km from each other. Grasshopper densities were estimated before treatments on June 21–22, 1987, on 7 dates after treatment from June 30 to August 10, 1987, on 11 dates from May 27 to August 16, 1988, and on 12 dates from May 24 to August 7, 1989.

Standard Carbaryl–Bran Bait Study Methods.—Carbaryl–bran bait was applied aerially to the North River and Elkhorn blocks in 1988 and to the Antelope–Bran block in 1991 (fig. 4). Applications were made with an Ayers Turbine Thrush S2RT aircraft equipped with a standard bait spreader and modified as described by Foster and Roland (1986). Generally, 2-percent carbaryl–wheat bran was applied at a rate of 1.68 kg/ha (0.03 kg AI/ha), using a 14-m swath width. Aircraft operated at approximately 240 km/hour from an altitude of 15 to 30 m. No precipitation occurred during or immediately after any of the treatments.

North River.—The 2,064-ha North River block was located about 39 km southwest of Watford City, ND

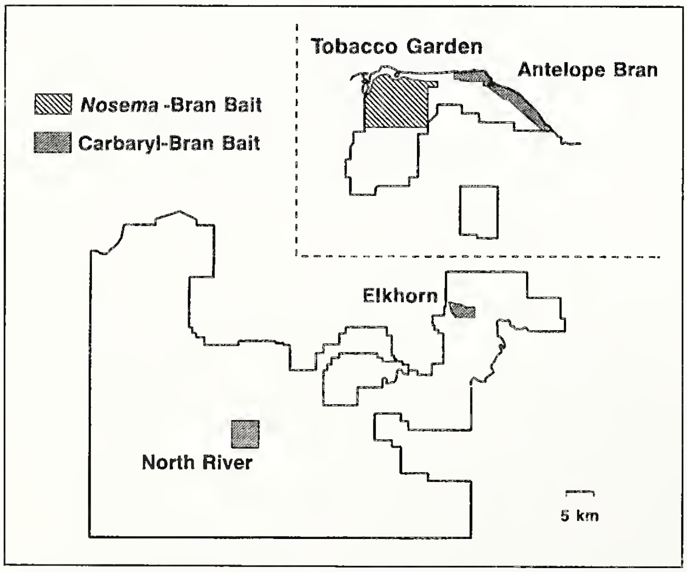

Figure 4—Areas within the demonstration block treated with aerial applications of *Nosema*-bran bait and carbaryl-bran bait.

(fig. 4). This block was a small portion of the much larger area designated North River in 1987 that was used as an untreated control area. The 2,064-ha North River block was treated with carbaryl-bran bait on June 17, 18 and 20, 1988. Ten evaluation sites were established in the center of adjacent sections (i.e., 259-ha blocks), or at least 1.6 km from each other. Ten untreated control sites were set up around the treatment block. These sites were 1.6–3.9 km from the treatment block and at least 1.6 km from each other. Pretreatment densities were estimated on June 13, 1988. Posttreatment counts were made 24 and 48 hours after treatment on 8 additional dates throughout the summer until August 15 and on 12 dates the following year from May 27 to August 8, 1989.

Elkhorn.—The 731-ha Elkhorn block was treated with carbaryl–bran bait on June 21, 1988. This block was located about 13.7 km southeast of Watford City (fig. 4). Before treatment, 10 evaluation sites were established at least 0.6 km apart within the treatment area, and 10 control sites were set up around the block. Control sites were located 0.6–2.8 km from the treatment block and were at least 1.2 km from each other. Pretreatment counts were made on June 15. Grasshopper densities were estimated 24 and 48 hours after treatment, on 8 subsequent dates from June 28 to August 17, 1988, and on 12 dates from May 26 to August 7, 1989.

Antelope–Bran.—The 2,550-ha Antelope–Bran block was treated on July 8 and 9, 1991. The block was located in the northeast corner of the Little Missouri National Grassland along Lake Sakakawea (fig. 4). Eight evaluation sites at least 0.6 km apart were established in the treated area, and three control sites were placed west and east of the treatment block. Control sites were at least 3 km from one another. Pretreatment counts were made on July 4. Posttreatment counts were conducted 3–4 days after treatment, on five dates from July 18 to August 13, 1991, and on six dates from June 3 to August 11, 1992.

Standard Malathion Spray Study Methods.—Five blocks of rangeland were treated aerially with malathion sprays as a corrective measure to control grasshopper infestations (fig. 5). Applications were made with 585 mL of Malathion-ULV concentrate per hectare (8 fluid oz/acre) (0.65 kg AI/ha or 0.58 lb AI/acre) with

either Cessna Ag Truck or Ayers Turbine Thrush S2RT aircraft. The Cessna Ag Truck aircraft were equipped with 8002 stainless steel Tee-Jet nozzle tips and operated with an assigned swath width of 30 m and an air-speed of 161 km/hour. The Ayers Turbine Thrush S2RT aircraft were equipped with 8004 stainless steel Tee-Jet nozzle tips and operated with an assigned swath width of 46 m and an airspeed of 241 km/hour. Both aircraft operated at an altitude of about 30 m.

Sather Lake.—Malathion was applied to the 15,022-ha Sather Lake block about 53 km west-southwest of Watford City (fig. 5). Prior to treatments, 29 evaluation sites were selected within the block near the center of alternate sections. Control evaluation sites were not established in this area. Rather, untreated grasshopper populations were monitored at 44 sites in the 12,605-ha North River block about 18 km southeast of the Sather Lake block (fig. 5). The North River control block and its evaluation sites were established originally to receive treatments. However, when it was decided not to treat the area, the established evaluation sites were used as control sites to compare with evaluation sites in the Sather Lake and Southwest blocks.

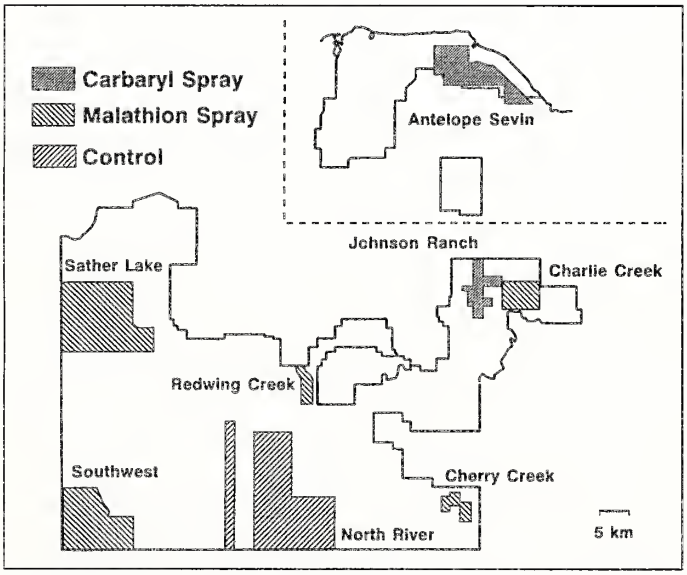

Figure 5—Areas within the demonstration block treated with aerial applications of carbaryl and malathion sprays. The North River block was not treated in 1987 to use as a control for the Sather Lake and Southwest block treatment areas.

The Sather Lake block was treated on July 7 and 8, 1987. The day before treatment, the area received significant rainfall; at the time of treatment, however, weather conditions were considered acceptable for use of malathion. Grasshopper densities were estimated before treatment on July 4, 1987, 2 days after treatment, on five additional dates from July 16 to August 12, 1987, and on June 26 and July 22 the following year. Evaluation sites within the North River control block were monitored on seven dates from June 23 to August 13, 1987, but were not monitored the following year.

Southwest.—The 8,935-ha Southwest block was located about 71 km southwest of Watford City (fig. 5). Seventeen evaluation sites were set up in alternate sections within the block. The evaluation sites within the North River block were used as control sites, as described earlier. The Southwest block was treated on July 5, 1987. Grasshopper populations were monitored in the Southwest block on the pretreatment date of July 3, 2 days after treatment, on five dates from July 15 to August 11, 1987, and June 28 and July 29 the following year. Untreated sites were monitored in the North River block, as described above. The species composition of grasshoppers was not recorded on the pretreatment sampling dates. Thus, only total grasshopper densities were analyzed.

Redwing Creek.—The 1,522-ha Redwing Creek block was located about 0.8 km west of the north unit of Theodore Roosevelt National Park (fig. 5). Ten evaluation sites at least 0.6 km apart were established throughout the treatment area. An additional 10 control sites were established around the block. These sites were 0.8–2.6 km from the treatment block and at least 0.8 km from each other. The Redwing Creek block was treated on July 5, 1990.

Pretreatment populations were estimated on July 1, 1990. Posttreatment populations were sampled 2 days after treatment, on six additional dates from July 12 to August 17, 1990, and on nine dates from June 4 to August 7, 1991.

Cherry Creek.—The Cherry Creek block consisted of 3,704 ha of rangeland and was located about 22.5 km southeast of Watford City (fig. 5). Ten evaluation sites

were established near the center of adjacent sections within the treatment area. Ten control sites were set up around the treatment block, 0.3–1.2 km from the edge of the block and at least 0.8 km from each other. The Cherry Creek block was treated on July 8, 1990. Grasshopper densities were estimated before treatment on July 4, 1990, 3 days after treatment, on six subsequent dates from July 17 to August 21, and on seven dates the following year from June 3 to August 12, 1991.

Charlie Creek.—The 1,347-ha Charlie Creek block was located about 45 km south-southeast of Watford City (fig. 5). Ten evaluation sites were set up 0.3–0.5 km apart within the treatment block. An additional 10 control sites were established around the block; these sites were at least 0.4 km apart and 0.4 km from the treated area. Malathion was applied on July 21, 1992. Grasshopper populations were sampled on July 17, before treatment, 2 days after treatment, and on August 6 and 18, 1992. Densities were again estimated on six dates the following year, from June 9 to July 19, 1993.

Standard Carbaryl Spray Study Methods.—Aerial applications of carbaryl were made to two blocks of rangeland as a corrective treatment to suppress grasshopper outbreaks (fig. 5). Carbaryl was applied as 1.46 L of Sevin-4-oil and diesel mix per hectare (20 oz/acre) (0.56 kg AI/ha or 0.50 lb AI/acre), with Ayers Turbine Thrush S2RT aircraft equipped with 8006 stainless steel Tee-Jet nozzle tips. All aircraft were operated with an assigned swath width of 46 m, an airspeed of 241 km/hour, and at an altitude of 15 to 46 m.

Antelope–Sevin Spray.—The 7,798-ha Antelope–Sevin spray block was treated with carbaryl spray on July 13-14, 1991. This block was located in the northeastern corner of the Little Missouri National Grassland, along Lake Sakakawea (fig. 5). Before treatment, 10 evaluation sites were set up uniformly in the treatment block, and 10 control evaluation sites were established around the block. Precount estimates were made on July 4, 1991. Posttreatment counts were made 2–3 days after treatment, on four dates from July 23 to August 13, and six dates the following year from June 1 to August 10, 1992.

Johnson Ranch.—The 2,940-ha Johnson Ranch block was located about 13 km southeast of Watford City (fig. 5). This block was treated with carbaryl spray on July 14–15, 1993. Before treatment, 10 evaluation sites were set up 0.3–1.2 km apart in the block, and 9 control sites were established 0.2–0.9 km from the treated area. Pretreatment estimates were made on July 12, 1993. Posttreatment populations were sampled 2–3 days after treatment, and on July 26, and August 3 and 9, 1993. The Johnson Ranch site was originally chosen to test a new aircraft tracking system.

Hot-Spot Treatments With Malathion Sprays Study Methods.—Three relatively small blocks of rangeland were treated aerially with malathion sprays in an attempt to prevent the growth of localized populations of grasshoppers into more widespread outbreaks (fig. 6). Applications were made with 585 mL of Malathion-ULV concentrate per hectare (8 oz/acre) (0.65 kg AI/ha or 0.58 lb AI/acre) with either Cessna Ag Truck, Ayers Turbine Thrush S2RT, or Piper Pawnee aircraft. These aircraft were equipped with 8002, 8004, and 8002 stainless steel Tee-Jet nozzle tips, respectively; operated with assigned swath widths of 30, 46, and 30 m, respectively, at airspeeds of 193, 241, and 161 km/hour, respectively, and at altitudes of 15 to 30 m.

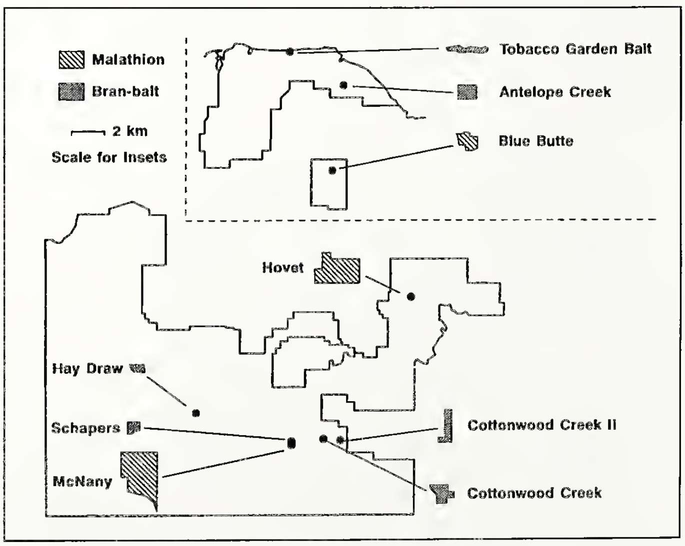

Figure 6—Areas within the demonstration block treated as hot spots with aerial applications of malathion spray or ground applications of carbaryl–bran bait.

***McNany.*—**The 259-ha McNany block was treated on July 2, 1988. This block was located 9.7 km south of the north unit of Theodore Roosevelt National Park (fig. 6). Before treatment, four evaluation sites were established within the McNany block and four control sites were established about 1.2 km from the treatment area. Pretreatment population estimates were made on June 29, 1988. Posttreatment counts were made 24 hours after treatment, on 6 additional dates from July 7 to August 10, 1988, and on 12 dates from May 26 to August 7, 1989.

***Blue Butte.*—**The 129-ha Blue Butte block was located 34.6 northeast of Watford City (fig. 6). This block was treated on July 19, 1989. Before treatment, six evaluation sites at least 300 m apart were set up within the treatment area. Six control sites were established around the treatment block, 200–1,200 m from the block and at least 900 m from each other. Pretreatment populations were estimated on July 8, 1989. Posttreatment counts were made 2 days after treatment, on July 28, and August 3 and 8, 1989, and the following year on 13 dates from May 24 to August 15, 1990.

***Hovet.*—**The 366-ha Hovet block was located 17.7 km southeast of Watford City (fig. 6). The block was treated with malathion on June 27, 1991. Five evaluation sites, about 300 m apart, were established within the treatment block and an additional five control sites were set up around the block. These sites were 100–700 m apart and at least 100 m from the treated area. Pretreatment populations were estimated on June 25, 1991. Posttreatment populations were assessed 2 days after treatment, on four dates from July 15 to August 12, 1991, and on six dates the following year from June 4 to August 10.

Hot-Spot Treatments With Carbaryl–Bran Bait

Study Methods.—Seven blocks of rangeland were treated with ground applications of carbaryl–bran bait in an attempt to prevent the growth of localized populations of grasshoppers (fig. 6). Applications were made with a Model 60 Brae-Mar applicator (Division of Peacock Industries, Saskatoon, SK, Canada) mounted to a truck (Boetel et al. 1995). The bait spreader was calibrated for a 12.2-m swath width when operating at a speed of 8 km/hour (5 mi/hour). Generally, bait was applied from a truck operating with two spreaders pointed in opposite directions. Baits contained 2-percent carbaryl and were applied at a rate of 2.24 kg/ha, or 0.04 kg AI/ha.

***Tobacco Garden–Bait.*—**The 60-ha Tobacco Garden–Bait block was located in the northern section of the Little Missouri National Grassland, adjacent to Lake Sakakawea (fig. 6). Before treatment, 10 evaluation sites were established about 170 m apart along a linear transect. Ten control sites were set up east, west, and south of the treatment block, within 0.3 km of the treated area. Carbaryl–bran bait was applied to the block on July 10, 1990. Because grasshopper populations remained high after the first treatment, 43 ha were again treated on July 18. Grasshopper densities were estimated before treatment on July 8, and 3 days after treatment on July 13. Populations were again assessed 5 days after the second treatment, and on July 30 and 6 and August 16, 1990. The following year, grasshoppers were sampled on eight dates from May 30 to August 6, 1991.

***Hay Draw.*—**The 10-ha Hay Draw block was located about 43 km southwest of Watford City (fig. 6). Three evaluation sites were established at least 225 m apart within the block, and three control sites, at least 300 m from each other, were established around the block. The Hay Draw block was treated first on June 16, 1990; it was treated again on June 22 because populations remained high after the first treatment. Initial populations were assessed on June 16, 1990, and then 2 days after treatment. Posttreatment densities were also estimated 2 days after the second treatment, and on six additional dates from July 9 to August 8, 1990. The following year, densities were estimated on May 23 and June 4, 1991. Because populations were high on these sample dates, the 10-ha block was treated with the insecticidal bait on June 11. Posttreatment counts were made 2 days after treatment, and on seven additional dates from June 19 to August 5, 1991.

***Cottonwood Creek.*—**The Cottonwood Creek block was located roughly 10 km south of the north unit of Theodore Roosevelt National Park (fig. 6). Six evaluation sites approximately 375 m apart were set up in the 85-ha block. Six control sites were established within 0.9 km of the block. Carbaryl–bran bait was applied

initially to a small section of the area of grasshopper infestation on June 18, 1990. The entire 85-ha block was then treated on June 25 and June 28, 1990. Initial pretreatment grasshopper densities were estimated on June 18, 1990. Posttreatment grasshopper counts were made 2 days after the last treatment, on seven dates from June 30 to August 15, 1990, and on eight dates the following year from May 29 to August 7, 1991.

Antelope Creek.—The 38-ha Antelope Creek block was located in the northeastern section of the Little Missouri National Grassland (fig. 6). Five evaluation sites about 260 m apart were established within the block, and five control sites, at least 400 m apart, were established surrounding the block. The Antelope Creek block was treated initially on June 22, and again on July 16, 1990. Initial pretreatment grasshopper counts were made on June 21. Posttreatment grasshopper density estimates were made 2, 14, and 20 days after the first treatment, 2 days after the second treatment, and on four additional dates from July 28 to August 16, 1990. Grasshopper population estimates were made the following year on five dates from May 22 to June 27, 1991.

Cottonwood Creek II.—The 41-ha Cottonwood Creek II block was located about 11 km south of the north unit of Theodore Roosevelt National Park (fig. 6). Five evaluation sites around 350 m apart were established in the treatment block. Five control sites at least 0.7 km apart were set up around the treated area. The Cottonwood Creek II block was treated with carbaryl–bran bait on June 18, 1991. Pretreatment grasshopper counts were made on June 14. Posttreatment grasshopper population estimates were made 3 days after treatment, on six dates from June 27 to August 7, 1991, and the following year on June 3 and 18 and July 3, 1992.

Schapers.—The Schapers block was located about 10 km south of the north unit of Theodore Roosevelt National Park (fig. 6). This block was part of the larger McNany block treated with malathion in 1988. Five evaluation sites were established about 60 m apart within the 46-ha treatment block. An additional five control sites, at least 150 m apart, were established around the treated area. Carbaryl–bran bait was applied on June 27, 1991. Pretreatment grasshopper densities were estimated on June 22, 1991. Posttreatment grasshopper counts were made 2 days after treatment, on four subsequent dates from July 14 to August 6, 1991, and on six dates from June 1 to August 10, 1992.

Extended Swath-Width Study Methods.—A study was conducted to determine whether the costs of aerial application of carbaryl–bran bait could be reduced by increasing the swath width during application. The results from the study were summarized briefly by Reuter et al. (1995) but will be provided in more detail here. In 1992 and 1993, four experiments were conducted to compare the efficacy of carbaryl–bran baits applied with 13.7-m (i.e., 45-ft) and 27.4-m (i.e., 90-ft) swath widths (fig. 7). Two-percent carbaryl–wheat bran was applied aerially with a Cessna-Ag Husky equipped with a Transland 20244 wheat bran spreader at a rate of 1.68 kg/ha (1.5 lb/acre) (0.03 kg AI/ha). For narrow swaths, the aircraft operated at a speed of approximately 240 km/hour and an altitude of 23 m. For wide swaths, the aircraft's operating altitude was increased to 46 m, and the bait flow rate was increased to a level that maintained an average application rate of 1.68 kg/ha. In theory, these adjustments would result in an increased swath of the drifting bran bait, reducing the number of passes required by the aircraft to treat the area of infestation.

Mead.—For this field experiment, 438- and 607-ha blocks were treated with carbaryl–bran bait using the 13.7- and 27.4-m swath widths, respectively. The two

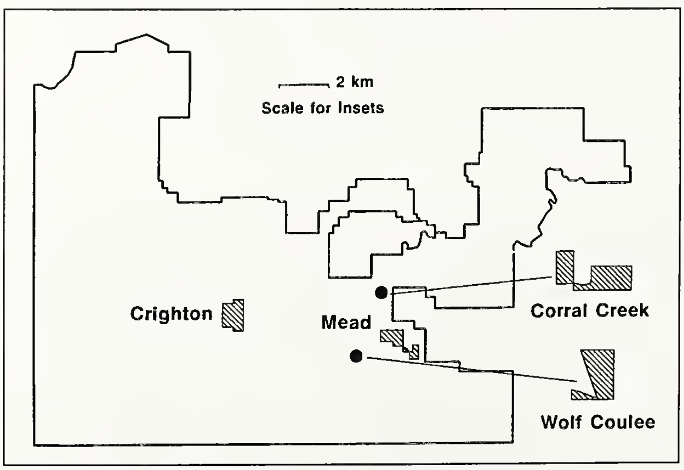

Figure 7—Areas within the demonstration block treated with aerial applications of carbaryl–bran bait as part of the extended swath-width study.

adjacent blocks were located about 8 km south of the north unit of Theodore Roosevelt National Park (fig. 7). The 13.7- and 27.4-m swath-width treatments were made on July 10 and 11, 1992, respectively. Before treatments, 10 evaluation sites 125–450 m apart were set up in each of the blocks, and 10 control evaluation sites, at least 500 m apart, were established around the 2 treatment blocks. Precount estimates were made on July 8, 1992. Grasshopper densities were also estimated 2, 4, and 10 days after treatment.

Crighton.—The 705- and 709-ha Crighton blocks were located about 40 km southwest of Watford City (fig. 7). These two adjacent blocks were treated with carbaryl–bran bait using 13.7-m and 27.4-m swath widths, respectively. Ten evaluation sites were established 200–300 m apart in each of the treatment blocks, and 10 control sites, 200–800 m apart and at least 125 m from the treated areas, were established around the treated areas. The 705- and 709-ha blocks were treated on July 8 and 9, 1992, respectively. Pretreatment counts were made on July 4, 1992. Grasshopper densities were estimated 2, 4, and 10 days after treatment. The Crighton blocks received heavy rains before and after treatments, and the areas remained wet for at least a week after treatments.

Wolf Coulee.—The Wolf Coulee blocks were located about 10 km south of the north unit of Theodore Roosevelt National Park (fig. 7). For the field study, 172- and 171-ha adjacent blocks were treated with carbaryl–bran bait using 13.7- and 27.4-m swath widths, respectively. Ten evaluation sites were set up 75–300 m apart within each of the blocks, and 10 control sites were established north of the treated areas. These sites were 100–375 m from the treated areas. The two blocks were treated on July 19, 1993. Pretreatment density estimates were made on July 17. Densities were also estimated 2, 4, and 10 days after treatment.

Corral Creek.—The two Corral Creek blocks were located adjacent to each other approximately 1.6 km south of the north unit of Theodore Roosevelt National Park (fig. 7). The 162- and 165-ha blocks were treated with carbaryl–bran bait using 13.7- and 27.4-m swath widths, respectively. Ten evaluation sites were set up 75–225 m apart within each of the blocks. Ten control sites 75–125 m apart were established around the treated areas. Applications were made on July 20, 1993. Pretreatment grasshopper populations were monitored on July 18. Posttreatment densities were estimated 2, 4, and 10 days after treatment.

Evaluation of GHIPM

Comparison of Sampling Intensity.—Adult grasshopper populations were sampled more intensely in the demonstration block than in the standard block (table 4). In the standard block, the average number of sections (i.e., 259-ha or 640-acre blocks) sampled was 278, or 24 percent of all available sections. In the demonstration block, an average of 570 sections, or 43 percent of all available sections, was sampled. The number of sites sampled for adult grasshoppers was also much greater in the demonstration block than in the standard block. Sampling intensity increased greatly in the standard block in 1992 and 1993, because local ranchers were concerned about the potential for grasshopper damage.

In 1989 and 1993, the only 2 years in which data were available, nymphal populations were also sampled more intensely in the demonstration block than the standard block. The average number of sections and sites sampled for grasshopper nymphs were 206 and 211, respectively, in the standard block. In contrast, an average of 523 sections and 693 sites were sampled for nymphs in the demonstration block in the 2 years.

Comparison of Areas Treated.—In the demonstration block, 62,314 ha (153,981 acres) were treated for grasshoppers from 1987 through 1993 (table 5). During the same interval, 121,110 ha (299,268 acres) were treated in the standard block (a 94-percent increase in the land area treated). In the standard block, insecticide was applied in only 4 of the 7 years; no treatments were made in 1988, 1989, or 1990. In the demonstration block, standard aerial treatments of insecticidal baits and sprays were administered in all years except 1989. However, the total areas treated in the demonstration block were much smaller than those in the standard block because of the use of hot-spot treatments. Fewer and larger areas of rangeland were treated in the standard block than in the demonstration block (fig. 8). In the standard block, except for a 95-ha (235-acre) area treated in 1993, all 5 treated areas exceeded 13,000 ha (32,124 acres). In contrast, the 28 areas treated in the demonstration block ranged from 10 to 15,022 ha (25 to 37,120 acres) (table 5, fig. 8). Most areas treated in the demonstration block were under 1,000 ha (2,471 acres).

Comparison of Toxicant Applied.—The IPM demonstration block received considerably less insecticide than the standard block (table 6). Almost all of the applications within the standard block were carbaryl sprays (table 5). At a rate of 0.56 kg AI per hectare (0.5 lb AI/acre) for carbaryl sprays and 0.0336 kg AI per hectare (0.03 lb AI/acre) for carbaryl baits, a total of 67,772 kg (149,410 lb) of active ingredient were applied in the standard block from 1987 through 1993.

A greater variety of treatments was made in the demonstration block. Of the 62,314 ha (153,981 acres) treated, 51 percent of the area received malathion spray (table 5). Aerial applications of carbaryl sprays, carbaryl baits, and *Nosema* baits constituted, 17, 14, and 17 percent of the treated areas, respectively. Ground applications of carbaryl baits were applied to less than 1 percent of the treated area. The total amount of insecticide active ingredient applied to rangeland from 1987 to 1993 was 2.5 times greater in the standard block than in the demonstration block (table 6).

Comparison of Treatment Costs.—Total cost of treatments over the 7-year period was 65 percent greater in the standard block than in the demonstration block (table 7). For carbaryl and malathion sprays, the costs of the toxicants were 3.4 and 1.5 times greater, respectively, than the costs of the application. In contrast, the costs

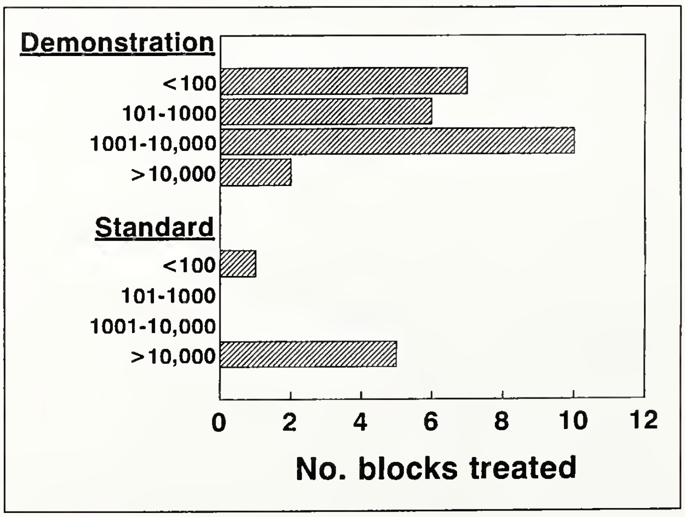

Figure 8—Frequency distribution of the sizes of areas treated in the demonstration and standard blocks from 1987 to 1993. Values are in hectares.

of applying bait with carbaryl or *Nosema* far exceeded the cost of treat bait itself. Application costs for ground treatment of carbaryl–bran bait were very low because treated areas were small and applications were made by APHIS personnel who were onsite to conduct surveys.

The cost of treatments (i.e., chemicals and application) in the demonstration block was much higher in 1987 than in other years because of the high cost of *Nosema* bait ($8.53/ha or $3.45/acre) and application ($13.27/ha or $5.37/acre). The *Nosema*–bran–bait treatment accounted for 45 percent of the total treatment costs in the demonstration block over the 7-year period. Had a more conventional treatment been applied to the Tobacco Garden block in 1987, instead of the more experimental *Nosema*–bran–bait treatment, the cost differences between the demonstration and standard block treatments would have been much greater.

Effect of Treatment Programs on Grasshoppers.— Mean densities of grasshoppers in the standard block ranged from a low of 2.50 ± 0.24 per m^2 *(n* = 218) in 1988 to a high of 7.28 ± 0.59 per m^2 *(n* = 191) in 1987 (fig. 9). In the demonstration block, mean densities ranged from a low of 1.60 ± 0.05 per m^2 *(n* = 439) in 1988 to a high of 4.95 ± 0.18 per m^2 *(n* = 705) in 1991. Figure 9 also shows that grasshopper population densities were more variable over time in the control block, ranging from 2.85 ± 0.55 per m^2 *(n* = 23) in 1990 to 11.42 ± 0.94 per m^2 *(n* = 31) in 1987. Comparisons of the control block with the other two blocks must be made with caution because different sampling methods were used. Results from the Kruskal–Wallis test indicated that densities in 1987 and 1992 were significantly greater in the standard block than in the demonstration block ($\chi^2 = 18.7$, $P < 0.001$ and $\chi^2 = 28.3$, $P < 0.001$, respectively). Densities were not significantly different in the other years ($P > 0.05$). These results indicate that overall grasshopper densities, after treatments, in the demonstration block were similar to densities in the standard block.

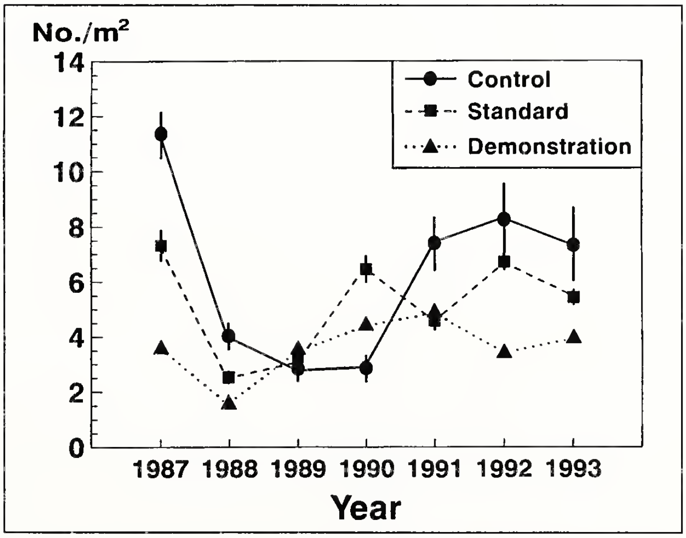

Figure 9—Densities of total grasshoppers within the demonstration, standard, and control blocks from 1987 to 1993. Estimates were determined from adult surveys taken in July or August of each year. Bars represent ± 1 SEM.

The frequency distributions of grasshopper densities in the standard and demonstration blocks (fig. 10) were significantly different in 1987 ($G^2 = 73.7$, df = 6, $P < 0.001$), 1988 ($G^2 = 21.9$, df = 4, $P < 0.001$), 1989 ($G^2 = 17.5$, df = 5, $P < 0.01$), 1990 ($G^2 = 38.1$, df = 6, $P < 0.001$), 1992 ($G^2 = 101.7$, df = 6, $P < 0.001$) and 1993 ($G^2 = 26.6$, df = 6, $P < 0.001$). No differences were detected in 1991 ($P > 0.05$). The higher frequency of grasshopper densities above 10 per m^2 in the standard block indicated that block's greater tendency to support larger outbreaks than the demonstration block, particularly in 1987, 1990, and 1992. Figure 10 also indicates relatively high densities of grasshoppers in the control block in several years. However, these frequency distributions may reflect differences in sample methods and the low sample sizes of the control block.

Evaluation of Specific Treatments in the Demonstration Block

Sixty-five species of grasshoppers were collected from 393 evaluation sites within the IPM demonstration block on the pretreatment sampling dates from 1987 to 1994 (table 8). *Melanoplus sanguinipes* (Fabricius) and *M. infantilis* Scudder were the two most abundant species, constituting 16.4 percent and 15.4 percent of all grasshoppers collected, respectively. Most (i.e., 46) species were relatively rare, constituting less than 1 percent of the total grasshopper collection. Of the top 10 species, *M. sanguinipes* and *M. infantilis* are considered mixed feeders, feeding on forbs and grasses. The next eight species, totaling 44.1 percent of all individuals, are

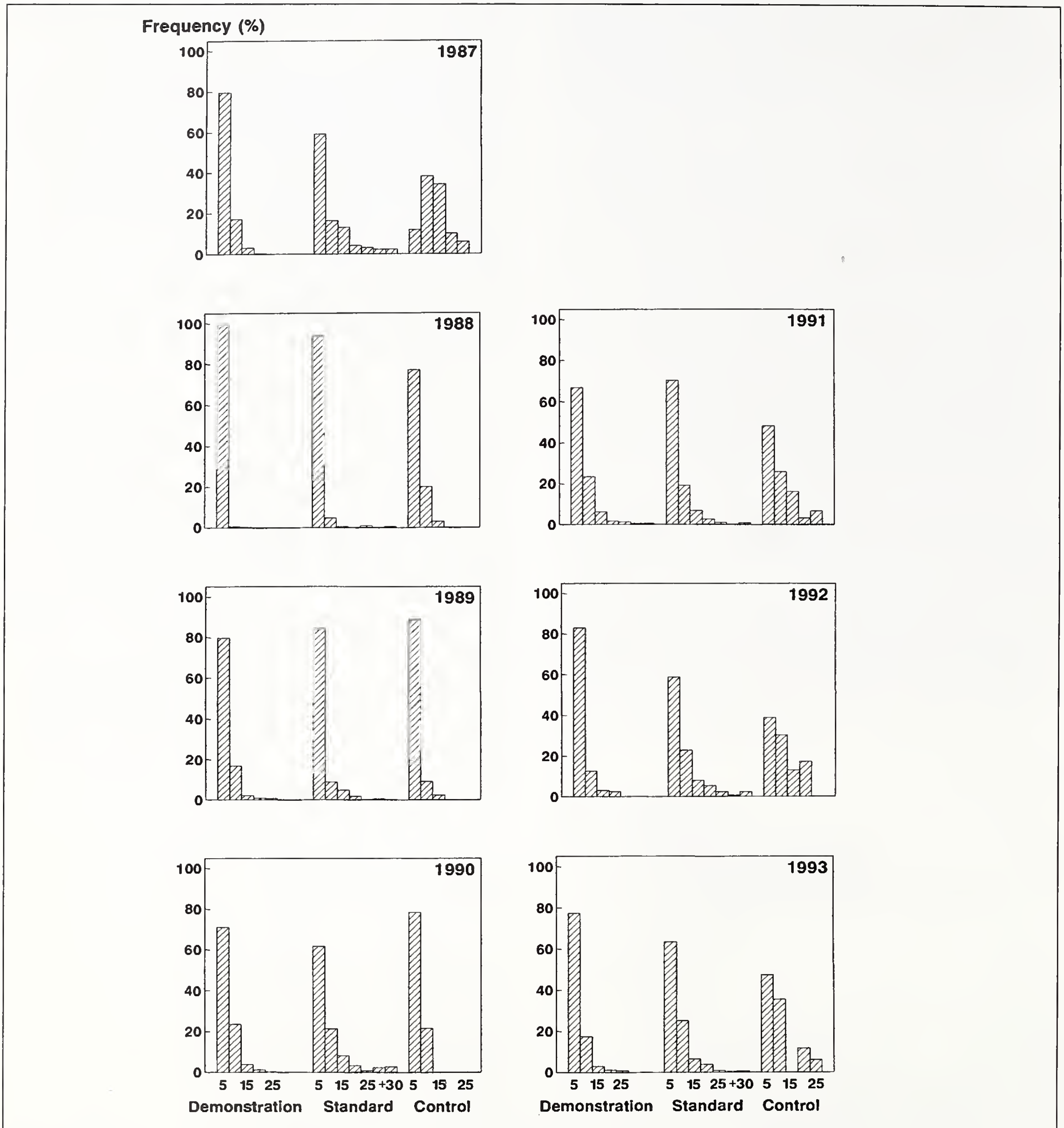

Figure 10—Frequency distributions of densities of total grasshoppers within the demonstration, standard, and control blocks from 1987 to 1993. Estimates were determined from adult surveys taken in July or August of each year and represent densities within sampled sections of rangeland.

considered grass feeders (Mulkern et al. 1964). There was a strong correlation between frequency and number of sites occupied ($r = 0.97$, $P < 0.001$; Spearman correlation analysis), suggesting that the most common grasshoppers also had the widest distributions. However, distributions of species varied considerably between specific treatment areas, as discussed later in this section.

***Nosema*–Bran Bait Study Results.—**

Tobacco Garden.—Thirty-three species of grasshoppers were collected on the pretreatment date at the treatment and control evaluation sites (table 9). *M. infantilis* was the most abundant species at the Tobacco Garden block, constituting 25.7 percent of individuals. *A. deorum* and *M. sanguinipes* constituted an additional 15.5 percent and 11.4 percent, respectively. All three species consume bran bait (Onsager et al. 1995). The dominant species at the control sites were *M. infantilis* (33.3 percent), *M. dawsonii* (Scudder) (25.3 percent), and *M. sanguinipes* (14.2 percent). *A. deorum* was not abundant at the control sites. At the time of treatment, 94.2 percent of the grasshoppers were in the nymphal stage, with first to fourth instars constituting 79.7 percent of grasshoppers (table 10).

The population dynamics of all grasshopper species together, bran-accepting species, and the two dominant species are shown in figure 11a–d. Mean pretreatment densities of all grasshoppers combined (minus the late-hatching species) at the treatment and control sites were 4.9 ± 0.8 and 6.7 ± 1.6 per m^2, respectively (table 11) and were not significantly different ($P > 0.05$, Kruskal–Wallis test). Most grasshoppers were bran acceptors; bran-rejecting and bran-vulnerable species had mean densities of less than 1 per m^2. Even pretreatment densities of the individual dominant species were quite low in the treated area (i.e., < 2 per m^2).

The mean density of all grasshoppers combined declined slightly by 26.4 ± 12.6 percent at the treated area within 10 days of application of *Nosema*–bran bait. But mean density also declined by 45.9 ± 9.9 percent at the control sites (table 11, fig. 11a). Results from multivariate repeated–measures analysis of variance of total grasshopper densities indicated a significant time effect ($F = 43.1$; df = 3, 20; $P < 0.001$) but no significant treatment effect or time × treatment interaction ($P > 0.05$). Densities of total grasshoppers were significantly lower during July 1987 ($F = 10.9$; df = 1, 22; $P < 0.01$), July 1988 ($F = 53.5$; df = 1, 22; $P < 0.001$), and July 1989 ($F = 9.4$; df = 1, 22; $P < 0.01$) than on the pretreatment date. However, there was no difference between densities at treatment and control sites.

Trends in the populations of bran-accepting species (fig. 11b) and *M. infantilis* (fig. 11c) were similar to trends for total grasshoppers. Mean grasshopper densities declined slightly in the treatment block and at control sites in 1987, remained low in 1988, and were slightly lower than pretreatment levels in 1989. Populations of *A. deorum* (fig. 11d) were also apparently not affected by the treatment because 1988 and 1989 populations were similar to pretreatment levels. Trends in untreated populations of *A. deorum* were difficult to detect because densities were very low at the control sites.

The results suggest that the *Nosema*–bait treatment caused little, if any, mortality of grasshoppers at the Tobacco Garden block. Because changes in grasshopper populations were similar at the treated and control sites, we believe that most or all of the observed reductions in grasshoppers after treatment was due to a natural decline in populations. There was no evident treatment effect 1 and 2 years after initial treatment.

Standard Carbaryl–Bran Bait Study Results.—

North River.—Twenty-three species of grasshoppers were collected from the 20 evaluation sites on the pretreatment date (table 12). Within the treatment block, the dominant species were *C. pellucida* (33.2 percent), *A. clavatus* (19.7 percent), *A. deorum* (13.2 percent), and *M. confusus* Scudder (9.5 percent). These species were similarly dominant at the control sites, constituting 52.7 percent of grasshoppers. *Trachyrhachys kiowa* Thomas was relatively abundant at the control sites but not in the treatment block. At the time of treatment, 40.1 percent of grasshoppers were adults (table 13) and 43 percent were in the fourth and fifth instar stage.

Mean pretreatment densities of all grasshoppers combined were 5.5 ± 1.6 and 1.6 ± 0.4 per m², respectively, at the treated and control sites (table 14). Pretreatment density of all grasshoppers combined was significantly greater at the treated sites ($F = 7.66$; df = 1, 18; $P < 0.05$; analysis of variance). Most grasshoppers in the treatment block were bran-accepting species; densities of bran rejectors and bran-vulnerable species were only 1.3 ± 0.5 and 0.01 ± 0.01 per m², respectively. Most of the bran rejectors were *A. clavatus*.

Density of all grasshoppers combined declined in the treated block by 36.0 ± 9.8 percent within 2 days of treatment, but it increased by 48.9 ± 21.6 percent at the control sites (table 14). By July 1988, density of all grasshoppers combined at the treated sites had declined by 72.2 ± 6.7 percent, but had not changed appreciably at the control sites. Densities at the control sites were relatively constant throughout June and July 1988. Total grasshopper populations rebounded to pretreatment levels a year after treatment (fig. 12a). Results from

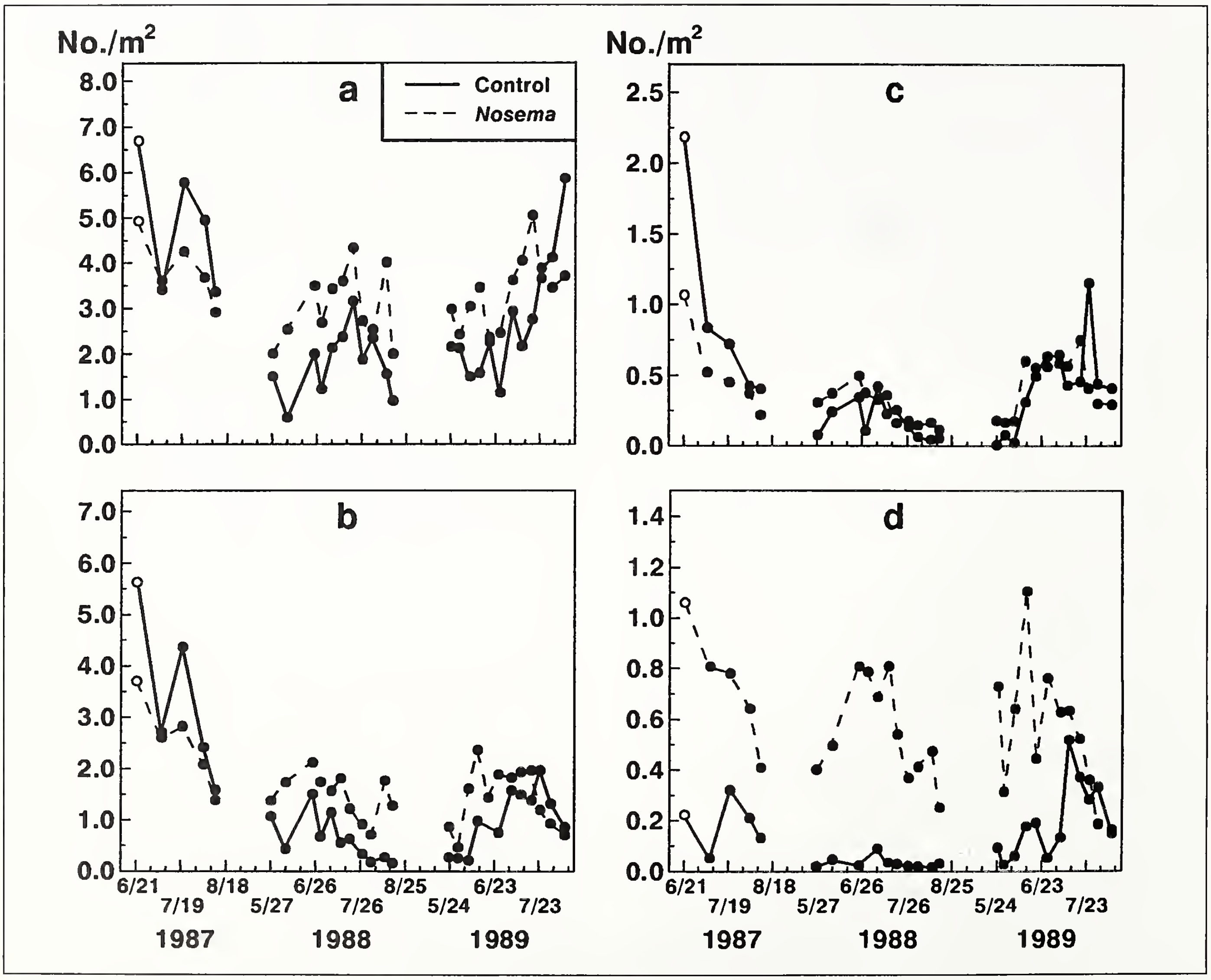

Figure 11—Population dynamics of total grasshoppers (a), bran-accepting species (b), *M. infantilis* (c), and *A. deorum* (d) at the *Nosema*–bran bait treatment block and at control sites over a 3-year period. The open circles represent pretreatment densities. Values indicate means. Standard errors omitted for clarity (but see table 11).

repeated-measures analysis of variance indicated a significant time effect ($F = 8.87$; df = 3, 51; $P < 0.001$) and time × treatment interaction ($F = 3.60$; df = 3, 51; $P < 0.05$). Contrasts between pretreatment and post-treatment dates indicated that densities were lower during July 1988 ($F = 23.8$; df = 1, 17; $P < 0.001$). There was no significant difference between pretreatment densities and average June 1989 or July 1989 densities ($P > 0.05$).

Populations of total bran-accepting species (fig. 12b) followed similar trends as total grasshoppers, declining by 57.8 ± 5.7 percent within 2 days of application of carbaryl–bran bait, and 83.8 ± 4.3 percent by July 1988 (table 14). Their densities remained low a year after treatment. Densities of total bran acceptors at the control sites remained relatively constant. Populations of *C. pellucida* (fig. 12d) declined by 76.1 ± 7.4 percent at

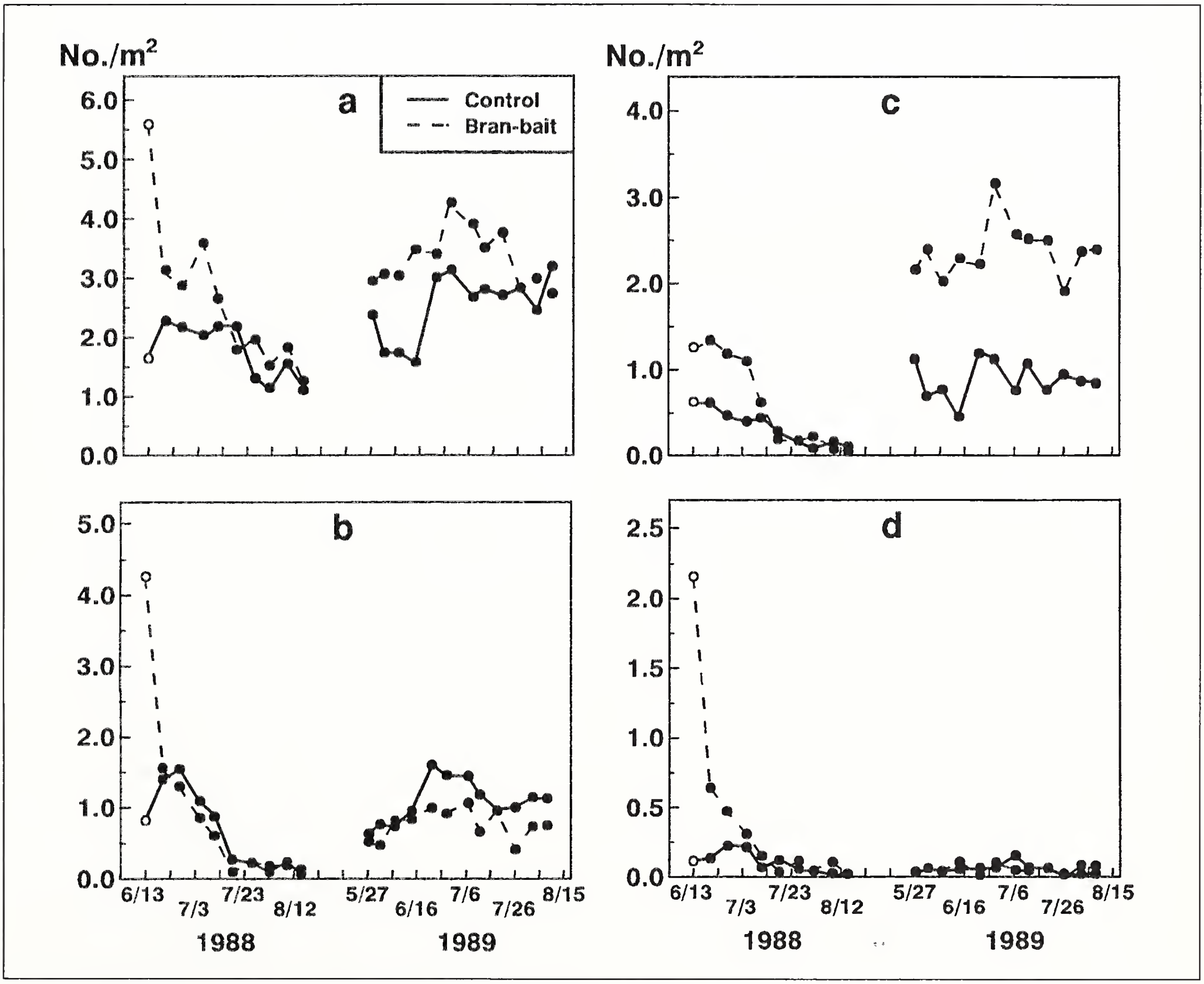

Figure 12—Population dynamics of total grasshoppers (a), bran-accepting species (b), bran-rejecting species (c), and *C. pellucida* (d) at the North River block treated with carbaryl–bran bait and control sites. Open circles represent pretreatment densities. Values indicate means. Standard errors omitted for clarity (but see table 14).

the treated sites and remained at low levels throughout the rest of 1988 and 1989. However, densities of *C. pellucida* at the control sites were too low to assess changes in untreated populations.

The mean density of bran-rejecting species, in contrast to that of bran acceptors, did not decline in the treatment block immediately after applications of carbaryl–bran bait (fig. 12c). Among bran rejectors, mean population levels increased a year after treatment and were consistently higher than pretreatment levels.

These results suggest that the carbaryl–bran bait treatment was effective in reducing grasshopper populations at the North River block. Treatments may have been effective in suppressing populations of bran-accepting species a year after treatment, but total grasshopper populations rebounded to pretreatment levels because of an increase in bran-rejecting species (i.e., predominantly *A. clavatus*).

Elkhorn.—The three dominant species in the Elkhorn block on the pretreatment date were *C. pellucida* (39.1 percent), *A. clavatus* (15.4 percent), and *M. infantilis* (11.2 percent) (table 15). The most abundant species at the control sites was *P. quadrimaculatum* (24.8 percent). *A. clavatus* and *M. infantilis* were also abundant at the control sites, but *C. pellucida* constituted only 1.2 percent of all grasshoppers collected there. At the time of treatment, 29.8 percent of all individuals were adults, and 47.5 percent were fourth and firth instars (table 13).

Initial grasshopper densities were quite low at the treatment and control sites (5.1 ± 1.1 and 2.7 ± 0.4 per m^2, respectively) (table 16). There was no significant difference between the two sets of evaluation sites in pretreatment densities of total grasshoppers, bran-rejecting species, bran-vulnerable species, *C. pellucida*, *A. clavatus*, and *M. infantilis* ($P > 0.05$). Only bran-accepting species were significantly more abundant in the bran-bait block than in the control sites ($P < 0.05$). Most grasshoppers were bran-accepting species, but bran rejectors constituted approximately 22 percent of individuals.

One day after treatment, densities of all grasshoppers combined declined by 54.6 ± 7.9 percent in the carbaryl–bran bait block, and did not change appreciably at the control sites (table 16, fig. 13a). By July, densities had declined by 78.2 ± 4.1 and 58.8 ± 6.6 percent at the treated and control sites, respectively. Results from repeated-measures analysis of variance of total grasshopper densities indicated a significant time effect ($F = 27.8$; df = 3, 54; $P < 0.001$) and time × treatment interaction ($F = 3.5$; df = 3, 54; $P < 0.05$). Contrasts between pretreatment and posttreatment dates indicated that average July 1988 and June 1989 densities were significantly lower than pretreatment densities ($F = 76.2$; df = 1, 18; $P < 0.001$ and $F = 12.2$; df = 1, 18; $P < 0.01$, respectively). There was no significant difference between July 1989 and pretreatment densities ($P > 0.05$), suggesting that populations rebounded to pretreatment levels during July 1989.

Densities of total bran-accepting species declined by 68.3 ± 5.0 percent immediately after treatment (table 16), and remained relatively low throughout the rest of 1988 and during 1989 (fig. 13b). Densities at the control sites remained constant. Densities of the bran acceptor *C. pellucida* declined by 77.7 ± 9.5 percent after treatment and remained at low levels thereafter (fig. 13d). However, control populations were too low to determine trends in untreated populations.

Populations of bran-rejecting species did not change appreciably immediately after treatment at either the treatment or control sites (fig. 13c). Mean densities of bran rejectors increased above pretreatment levels a year after treatment.

The results from the Elkhorn block experiment suggest that the carbaryl–bran bait treatment was moderately effective in suppressing grasshopper populations in the year of treatment and may have suppressed populations of bran acceptors a year after treatment. However, the carbaryl–bran bait did not seem to suppress second-year populations of total grasshoppers because of an increase in bran-rejecting species (i.e., predominantly *A. clavatus*) in 1989. Results should be interpreted with caution because accurate comparisons between the treated and control sites cannot be made. Treated and control sites differed in grasshopper species composition and densities.

Antelope–Bran.—*M. infantilis*, *M. sanguinipes*, and *Phoetaliotes nebrascensis* (Thomas) were the dominant grasshopper species at the carbaryl–bran bait treatment and control sites. These three species constituted 62.7 of all grasshoppers at the carbaryl–bran treatment sites and 56.7 percent of all grasshoppers at the control sites (table 17). All three are bran-accepting or bran-vulnerable species. At the time of treatment, 47.5 percent of grasshoppers were fourth or fifth instars, whereas adults constituted 29.8 percent of individuals (table 13).

Mean pretreatment densities of all grasshoppers combined at the treatment and control sites were 20.9 ± 5.6 and 13.3 ± 7.4 per m^2, respectively (table 18). Most grasshoppers in the treatment block were bran-accepting and bran-vulnerable species; the density of bran rejectors was < 2 per m^2. There was no significant difference in pretreatment densities of any group between the treated and control sites ($P > 0.05$).

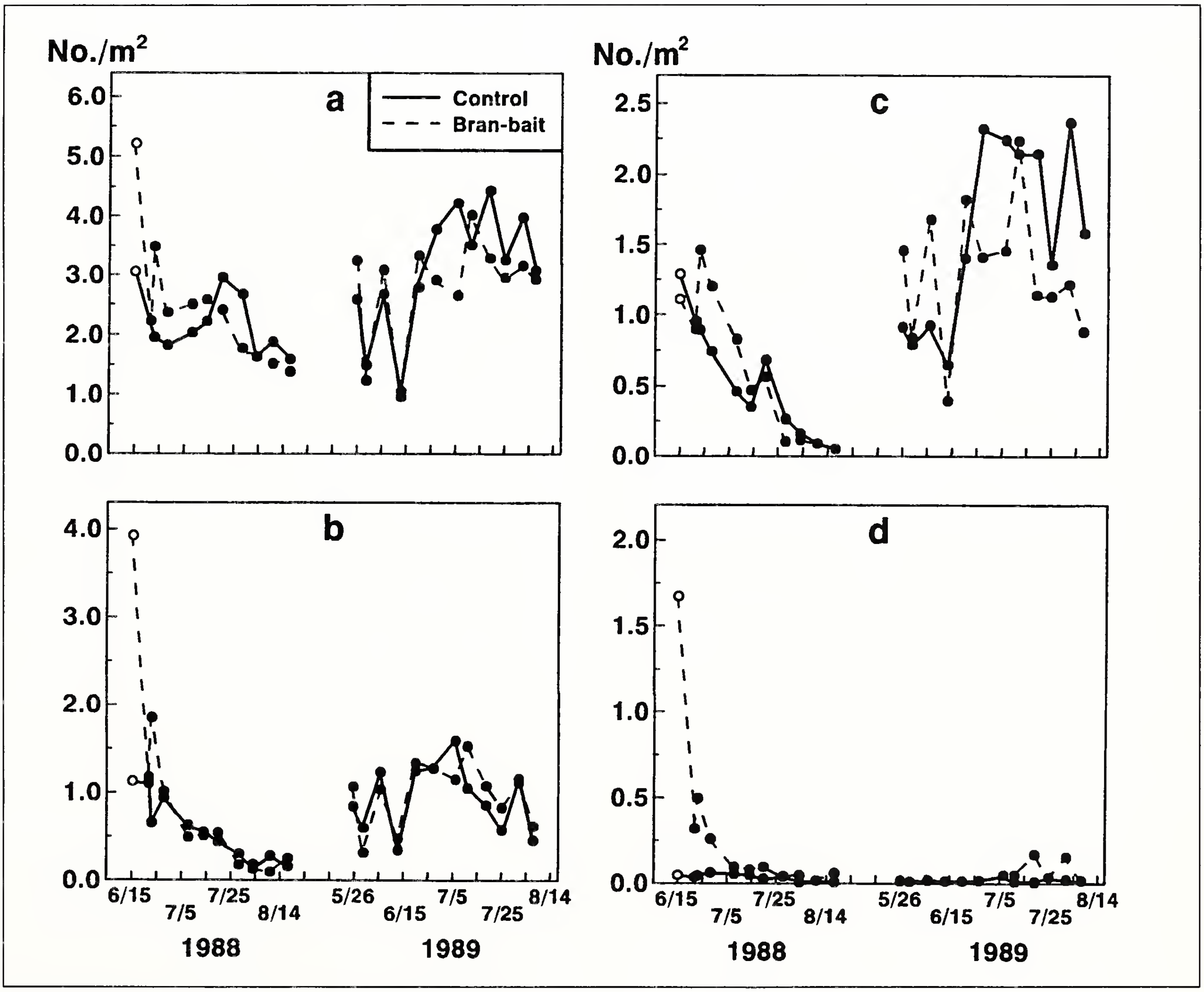

Figure 13—Population dynamics of total grasshoppers (a), bran-accepting species (b), bran-rejecting species (c), and *C. pellucida* (d) at the Elkhorn block treated with carbaryl–bran bait and control sites. The open circles represent pretreatment densities. Values indicate means. Standard errors omitted for clarity (but see table 16).

Densities of total grasshoppers did not change appreciably 4 days after treatment with carbaryl–bran bait (table 18, fig. 14a). However, by mid- to late July, densities at the treated sites had declined by 43.7 ± 7.9 percent, whereas control populations remained relatively constant after the treatment date. Densities within the treated area remained relatively low a year after treatment. Results from repeated-measures analysis of variance indicated a significant time effect ($F = 17.8$; df = 3, 27; $P < 0.001$) and time × treatment interaction ($F = 2.7$; df = 3, 27; $P < 0.07$). Second-year densities were significantly lower than pretreatment densities ($P < 0.05$).

Populations of all bran-accepting species (fig. 14b) and of the bran-accepting species *M. infantilis* (fig. 14e) and *M. sanguinipes* (fig. 14f) followed trends similar to those for all grasshoppers combined. Densities were not reduced appreciably immediately after treatment but did eventually decline relative to controls. Densities also remained low the following year. In contrast, populations of total bran-vulnerable species (fig. 14d) and of *P. nebrascensis* (fig. 14g) declined quickly after treatment and remained relatively low for the duration of the study. Their densities did not decline at the control sites immediately after treatment.

Populations of bran-rejecting species (fig. 14c) did not decrease at the treated sites immediately after treatment. Second-year densities of the bran rejectors during July were similar to pretreatment levels.

The results from the Antelope–Bran experiment suggest that application of carbaryl–bran bait was moderately effective in reducing grasshopper populations but that posttreatment densities were still quite high (i.e., > 10 per m^2). Second-year populations may have been suppressed by the treatments. Interestingly, the bran-vulnerable species (i.e., predominantly *P. nebrascensis*), seemed to be more affected by treatment than the bran-accepting species.

Standard Malathion Spray Study Results.—

Sather Lake.—*A. deorum*, *M. sanguinipes*, *M. infantilis*, and *A. elliotti* were the dominant grasshopper species at the Sather Lake block on the pretreatment date, constituting 26.2, 20.7, 14.6, and 9.8 percent of all individuals, respectively (table 19). *A. deorum* and *M. sanguinipes* were also the two dominant species at the untreated North River block, constituting 37.4 percent of all grasshoppers. At the time of treatment with malathion, 54.5 percent of grasshoppers were adults (table 20).

Pretreatment densities of all grasshoppers combined at the Sather Lake and North River blocks were 9.2 ± 1.0 and 9.9 ± 1.2 per m^2, respectively (table 21). Mean density of *A. deorum*, the most abundant species at the Sather Lake block, was only 2.4 ± 0.4 per m^2. Pretreatment densities of total grasshoppers and *M. sanguinipes* were similar at the Sather Lake and North River blocks ($P > 0.05$) (table 21). Pretreatment densities were significantly greater at the Sather Lake block for *A. deorum* ($\chi^2 = 4.2$, df = 1, $P < 0.05$) and *M. infantilis* ($\chi^2 = 6.6$, df = 1, $P < 0.01$).

Density of all grasshoppers combined at the Sather Lake block declined by 94.1 ± 1.1 percent immediately after treatment with malathion, and did not change appreciably at the untreated North River block (table 21, fig. 15a). Densities remained low the rest of 1987 and the following year at the Sather Lake block. It is not known whether untreated populations declined similarly a year after treatment because the North River block was not monitored as part of the study in 1988. However, results from the adult survey conducted in the North River block suggest that populations were also relatively low during 1988 (mean = 1.5/m^2, $n = 38$).

Densities of *A. deorum*, *M. sanguinipes*, and *M. infantilis* at the Sather Lake block also declined by more than 91 percent immediately after treatment but remained unchanged at the North River block (table 21). Populations of these species also remained low for the rest of 1987 and during 1988 (fig. 15b,c,d).

As expected, the malathion spray caused a large and rapid reduction in grasshopper populations. Even though the control sites were located relatively far from the treatment site, it is likely that the large reduction in grasshopper populations at the Sather Lake block was due mainly to treatment effects.

Southwest.—Pretreatment density of total grasshoppers was 9.0 ± 1.8 per m^2 and decreased 83.3 ± 11.5 percent

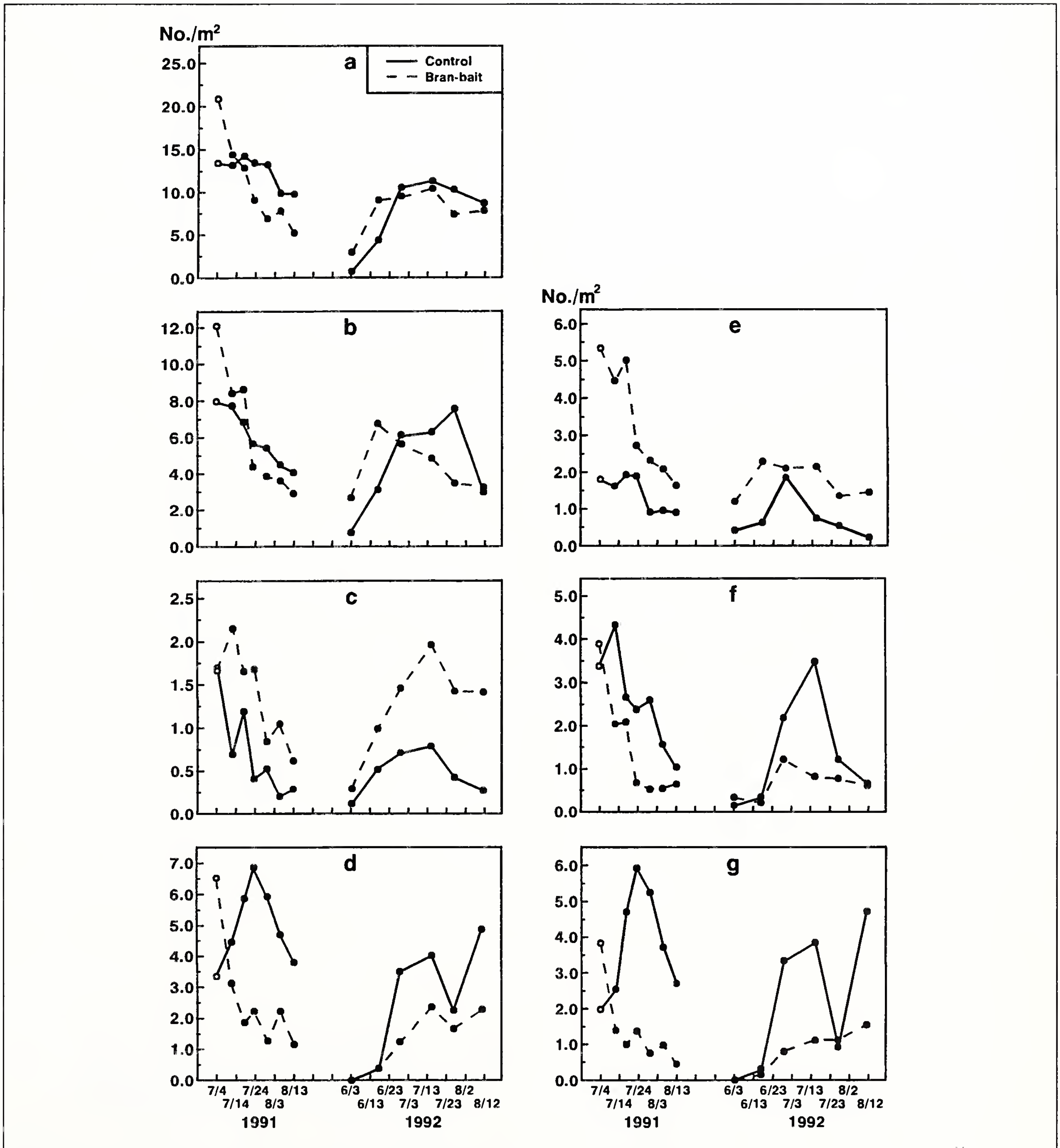

Figure 14—Population dynamics of total grasshoppers (a), bran-accepting species (b), bran-rejecting species (c), bran-vulnerable species (d), *M. infantilis* (e), *M. sanguinipes* (f), and *P. nebrascensis* (g) at the Antelope–Bran block treated with carbaryl–bran bait and control sites. The open circles represent pretreatment densities. Values indicate means. Standard errors omitted for clarity (but see table 18).

immediately after treatment (fig. 16). The population of total grasshoppers at the North River control sites did not change appreciably over the same time interval. Densities of grasshoppers remained at low levels the rest of 1987 and the following year (fig. 16). Populations at the control sites were not monitored the following year. Also, changes in populations of individual species were not determined at the Southwest block. Nevertheless, the large reduction in total grasshoppers indicates that all dominant species were affected by the treatment.

Redwing Creek.—The four dominant species of grasshoppers at the Redwing Creek block were *M. infantilis* (20.6 percent), *T. kiowa* (17.4 percent), *A. elliotti* (12.8 percent), and *A. deorum* (9.8 percent) (table 22). These species were also abundant at the control sites, constituting 59.2 percent of grasshoppers. *Amphitornus coloradus* (Thomas) and *P. quadrimaculatum*, together, also constituted 24.5 percent of grasshoppers at the control sites. At the time of treatment, adults constituted only 13.0 percent of grasshoppers at the Redwing Creek

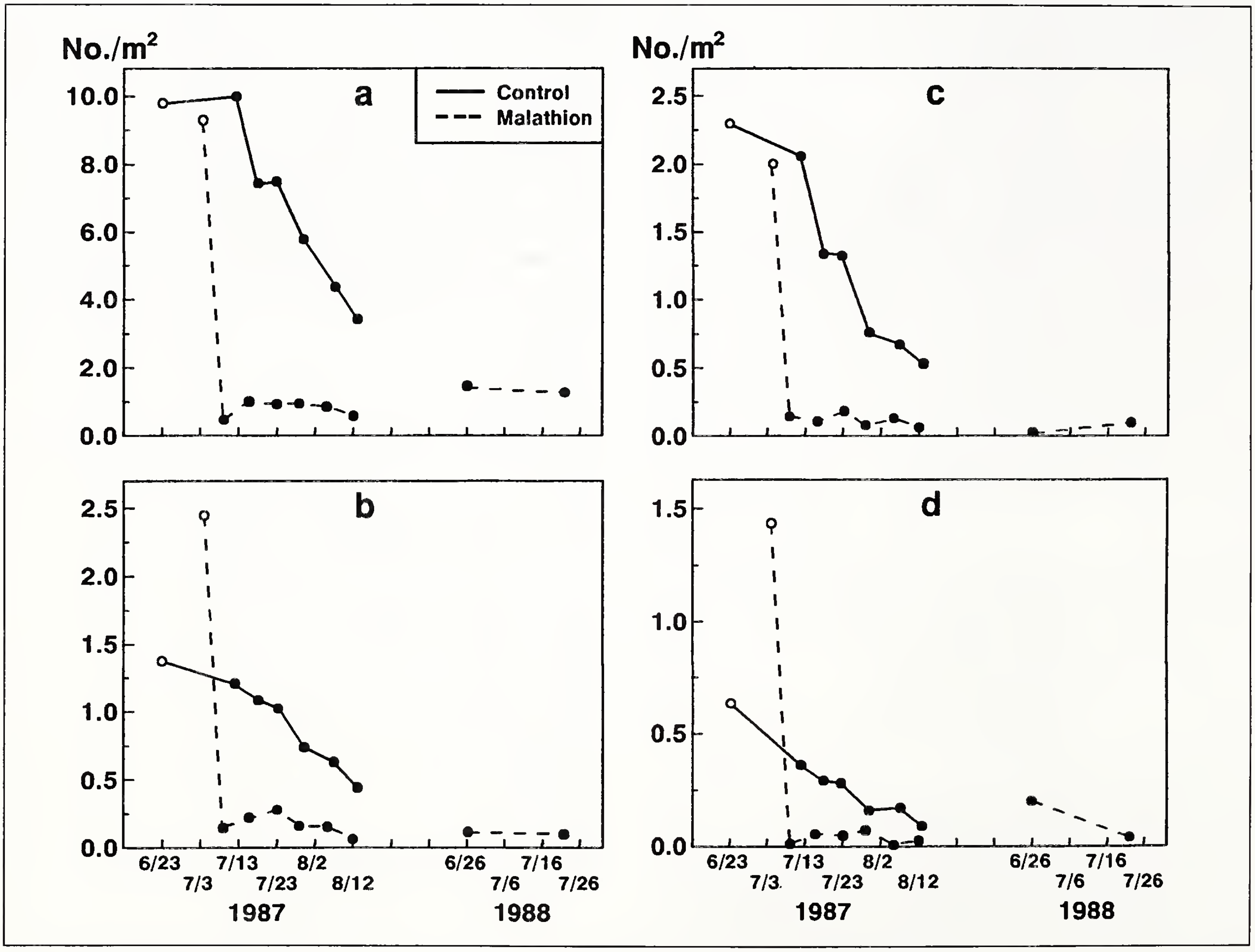

Figure 15—Population dynamics of total grasshoppers (a), *A. deorum* (b), *M. sanguinipes* (c), and *M. infantilis* (d) at the Sather Lake block treated with standard malathion spray and the North River control block. The open circles represent pretreatment densities. Values indicate means. Standard errors omitted for clarity (but see table 21).

block (table 20). Most grasshoppers were fourth and fifth instars.

Pretreatment densities of grasshoppers at the Redwing Creek block and control sites were 11.2 ± 2.8 and 6.8 ± 2.7 per m^2, respectively (table 23). *M. infantilis*, the most abundant species in the treatment block, had a pretreatment density of only 2.6 ± 0.7 per m^2. Pretreatment density of total grasshoppers was significantly greater at the malathion-treatment block than at control sites ($\chi^2 = 3.6$, df = 1, $P < 0.06$). There was no significant difference in densities of any individual species analyzed between the treated and control sites ($P > 0.05$).

Total grasshoppers declined by 91.0 ± 3.2 percent in the malathion-treatment block immediately after treatment, and increased by a mean 18.9 ± 14.0 percent at the control sites (table 23, fig. 17a). Populations remained low for the rest of 1990. Average July 1990 and July 1991 densities were reduced similarly. Results from repeated measures analysis of variance indicated a significant time effect ($F = 48.7$; df = 2, 36; $P < 0.001$) and time × treatment interaction ($F = 38.2$; df = 2, 36; $P < 0.001$). Contrasts between the pretreatment and July 1990 and July 1991 densities were also significant ($F = 73.2$; df = 1, 18; $P < 0.001$ and $F = 60.7$; df = 1, 18; $P < 0.001$, respectively).

Pretreatment densities of *M. infantilis* in the treatment block declined by 88.3 ± 10.0 percent immediately after application of malathion (table 23, fig. 17b). Mean density of *M. infantilis* also declined slightly at the control sites, but quickly increased to near pretreatment levels. Populations of *T. kiowa* (fig. 17c), *A. elliotti* (fig. 17d), and *A. deorum* (fig. 17e) at the treatment sites followed similar trends as total grasshoppers. Mean densities of *T. kiowa* and *A. elliotti* at the control sites a year after the treatment date were lower than pretreatment levels, whereas second-year populations of *A. deorum* increased to pretreatment levels.

The results from the Redwing Creek experiment suggest that grasshopper populations were reduced immediately after treatment with malathion and stayed at low levels for the rest of the year. Second-year grasshopper populations were also relatively low, but it cannot be concluded that malathion caused this reduction. Second-year populations were also lower at the control sites.

Cherry Creek.—The three dominant species at the Cherry Creek block on the pretreatment sampling date were *M. infantilis* (28.3 percent), *M. sanguinipes* (17.4 percent), and *A. deorum* (13.2 percent) (table 24). These species also constituted 49.4 percent of grasshoppers at the control sites. *Melanoplus femurrubrum* (DeGeer) was also abundant at the control sites, constituting 17.7 percent of individuals. Adults constituted 15.8 percent of individuals, while fourth and fifth instars constituted 70.7 percent of all grasshoppers (table 20).

Pretreatment densities of total grasshoppers at the treatment and control sites were 9.9 ± 1.8 and 12.8 ± 3.4 per m^2, respectively (table 25). Density of the most abundant species, *M. infantilis*, at the treatment sites was 2.8 ± 0.6 per m^2. There were no significant differences in densities of total grasshoppers or of the three dominant species between the treatment block and control sites ($P > 0.05$) (table 25).

Immediately after treatment with malathion, total grasshopper density declined by 88.1 ± 4.0 percent in the treatment block but did not change appreciably at the

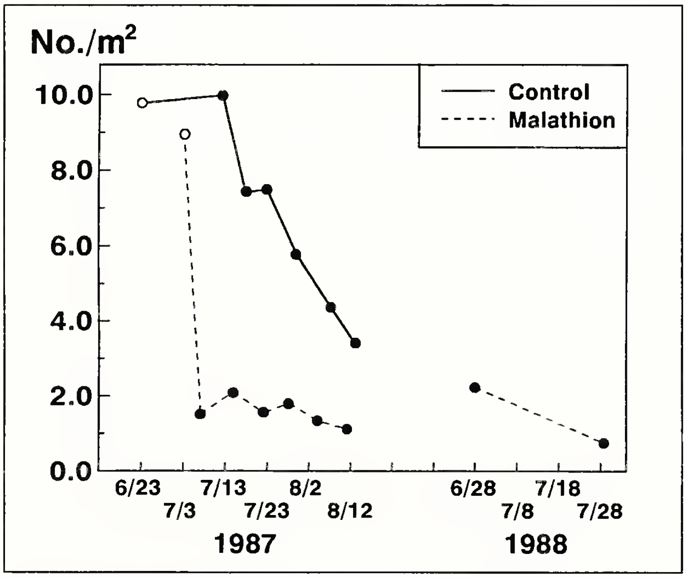

Figure 16—Population dynamics of total grasshoppers at the Southwest block treated with standard malathion spray and the North River control block. The open circles represent pretreatment densities. Values indicate means. Standard errors omitted for clarity.

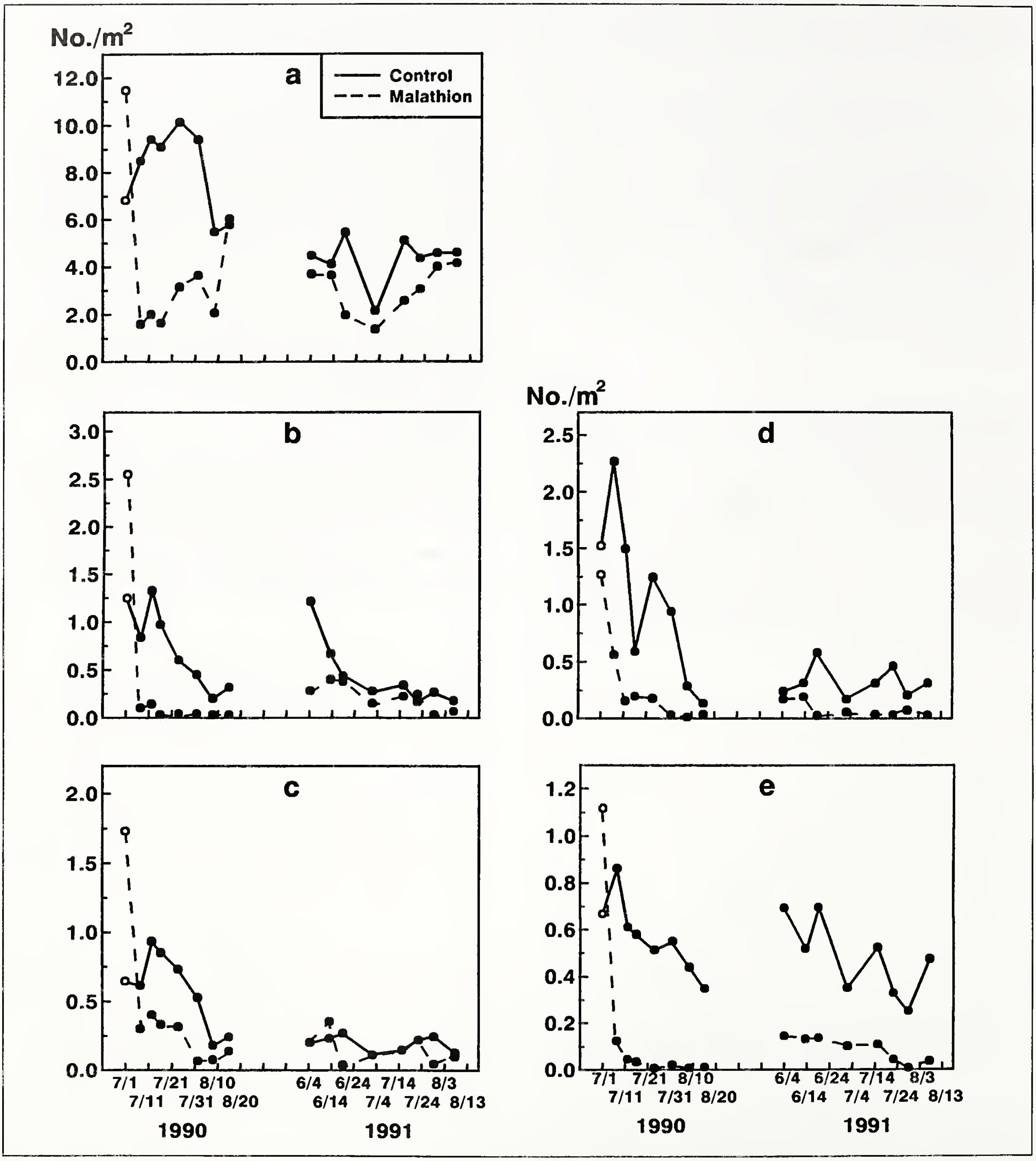

Figure 17—Population dynamics of total grasshoppers (a), *M. infantilis* (b), *T. kiowa* (c), *A. elliotti* (d), and *A. deorum* (e) at the Redwing block treated with standard malathion spray and control sites. The open circles represent pretreatment densities. Values indicate means. Standard errors omitted for clarity (but see table 23).

control sites (table 25, fig. 18a). Densities remained low for the rest of 1990, and were reduced by 69.5 ± 5.2 percent during July 1991. In contrast, total densities of grasshoppers were relatively high during July 1990 and 1991 at the control sites. Results from repeated measures analysis of variance indicated a significant time effect ($F = 19.5$; df = 3, 51; $P < 0.001$) and time × treatment interaction ($F = 15.1$; df = 3, 51; $P < 0.001$). Contrasts between pretreatment and posttreatment dates indicated that densities were reduced significantly during July 1990 ($F = 55.4$; df = 1, 17; $P < 0.001$), June 1991 ($F = 14.4$; df = 1, 17; $P < 0.01$), and July 1991 ($F = 17.4$; df = 1, 17; $P < 0.001$).

Density of *M. infantilis* declined by 98.2 ± 1.1 percent in the treatment block, but also declined by 58.1 ± 13.3 percent at the control sites (table 25, fig. 18b). Populations of *M. infantilis* remained low in both sets of evaluation sites for the rest of 1990. Densities of *M. infantilis* increased during June 1991, but densities in July 1991 were considerably lower than pretreatment densities. Populations of *M. sanguinipes* (fig.18c) followed trends similar to those for all grasshoppers combined. Mean densities of *A. deorum* (fig. 18d) declined immediately after the treatment date in both the treated and control sites. Second-year populations of *A. deorum* at the control sites were similar to pretreatment populations, whereas densities remained low in the treatment block.

The results from the Cherry Creek experiment suggested that treatment caused a large and immediate reduction in the population of grasshoppers. However, some species, such as *M. infantilis*, may have declined naturally in the first year of the study (fig. 18b). Second-year populations of total grasshoppers were also suppressed in the treated area.

Charlie Creek.—Of the 34 species of grasshoppers collected at the Charlie Creek block on the pretreatment date in 1992, *M. infantilis* constituted 42.7 percent of all individuals (table 26). *M. sanguinipes* and *A. deorum* constituted an additional 29.3 and 11.5 percent, respectively. These three species also constituted 56.5 percent of individuals at the control sites. At the time of treatment, 73.1 percent of the grasshoppers were fourth and fifth instars (table 20).

Pretreatment densities of total grasshoppers at the malathion-treated and control sites were 15.8 ± 1.7 and 20.9 ± 3.6 per m^2, respectively (table 27). Pretreatment densities of *M. infantilis* and *M. sanguinipes* at the treated sites were 6.6 ± 1.1 and 4.4 ± 0.9 per m^2, respectively. Pretreatment densities of total grasshoppers, *M. sanguinipes*, and *A. deorum* in the treatment block and control sites were not significantly different ($P > 0.05$). Pretreatment densities of *M. infantilis* were significantly greater in the malathion-treatment block than the control sites ($\chi^2 = 6.8$, df = 1, $P < 0.01$).

Densities of all grasshoppers combined decreased in the malathion-treatment block by 98.5 ± 0.75 percent immediately after treatment but did not change appreciably at the control sites (table 27, fig. 19a). Densities remained low for the rest of 1992 and throughout 1993. Results from repeated-measures analysis of variance indicated a significant time effect ($F = 89.2$; df = 2, 34; $P < 0.001$), and time × treatment interactions ($F = 50.7$; df = 2, 34; $P < 0.001$). Contrasts between pretreatment and posttreatment densities indicated that pretreatment densities were significantly higher than June 1993 ($F = 296.8$; df = 1, 17; $P < 0.001$) and July 1993 ($F = 100.1$; df = 1, 17; $P < 0.001$) densities.

Densities of the dominant species of grasshoppers also decreased substantially immediately after treatment with malathion (table 27, fig. 19b,c,d). Their densities also remained low for the rest of 1992 and in 1993.

Results from the Charlie Creek experiment suggest that malathion caused the large reductions in grasshopper populations and may have been responsible for suppressing populations a year after treatment.

Standard Carbaryl Spray Study Results.—

Antelope–Sevin Spray.—Twenty-eight species of grasshoppers were collected at the Antelope–Sevin Spray block and control evaluation sites on the pretreatment date in 1991 (table 28). *M. infantilis* was the dominant species, constituting 36.3 and 26.3 percent of grasshoppers at the treatment block and control sites, respectively. *C. pellucida* and *M. sanguinipes* were also relatively abundant at the control sites. On the pretreatment date, 19.2 percent of grasshoppers collected were

adults (table 29). Fourth and firth instars constituted 62.6 percent of grasshoppers collected.

Pretreatment densities of all grasshoppers combined at the carbaryl treated and control sites were 15.8 ± 4.8 and 18.2 ± 4.7 per m², respectively (table 30). *M. infantilis* was the only species with a density greater than 2 per m². There was no significant difference between the treatment and control evaluation sites in densities of total grasshoppers or *M. infantilis* on the pretreatment sampling date ($P > 0.05$).

The total population of grasshoppers declined by 94.0 ± 1.9 percent at the carbaryl-treatment sites immediately after treatment (table 30, fig. 20a). Control populations declined slightly by 31.0 ± 7.7 percent over the same time interval. Densities at the treated sites remained low through 1991 and 1992. Grasshopper densities at con-

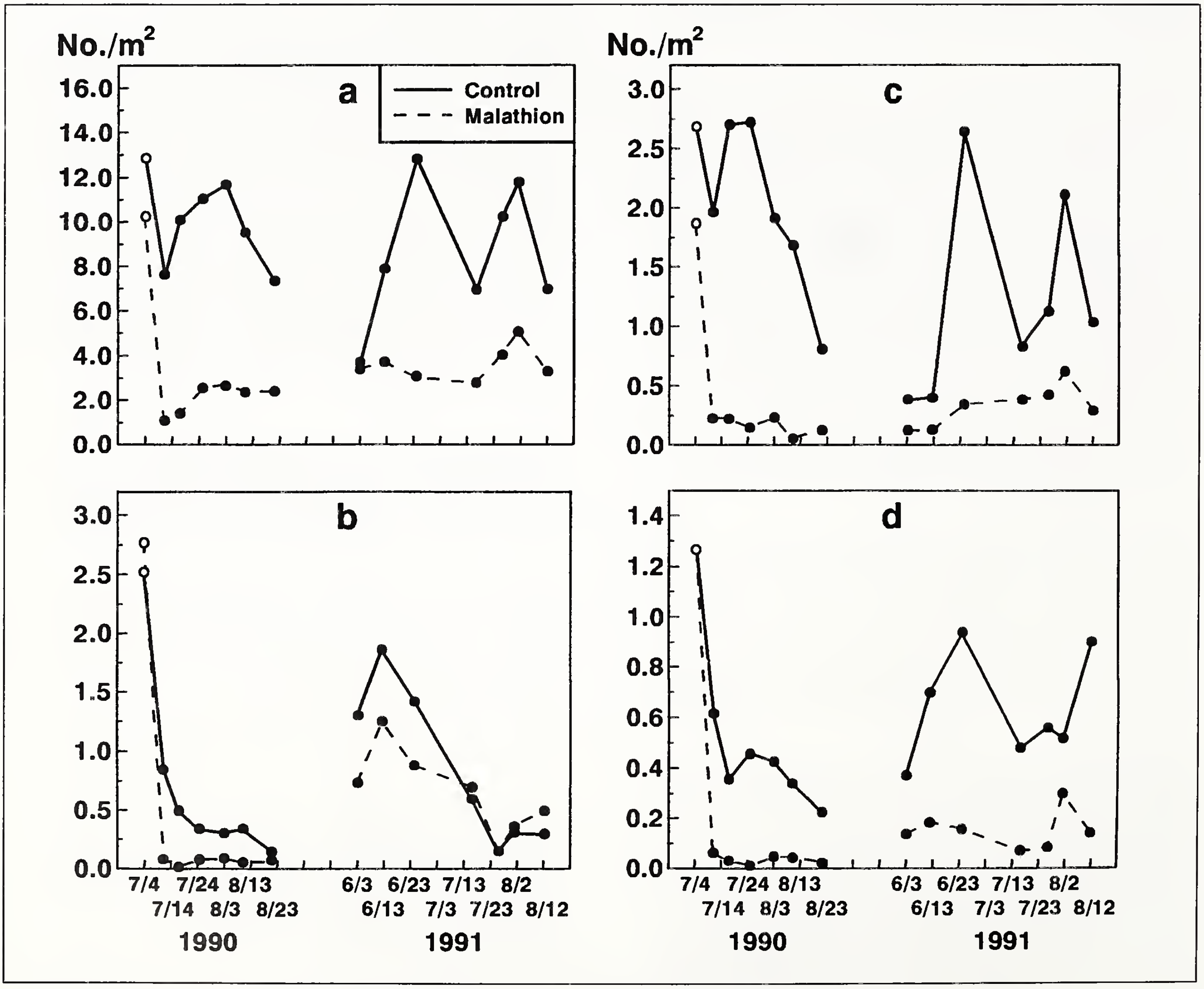

Figure 18—Population dynamics of total grasshoppers (a), *M. infantilis* (b), *M. sanguinipes* (c), and *A. deorum* (d) at the Cherry Creek block treated with standard malathion spray, and control sites. The open circles represent pretreatment densities. Values indicate means. Standard errors omitted for clarity (but see table 25).

trol sites were also lower in 1992 but remained higher than densities at the treatment sites. Results from repeated-measures analysis of variance of pretreatment and posttreatment densities indicated a significant time effect ($F = 24.9$; df = 3, 16; $P < 0.001$) and time × treatment interaction ($F = 16.6$; df = 3, 16; $P < 0.001$). Contrasts between pretreatment and posttreatment densities indicated that July 1992 densities were significantly lower than pretreatment densities ($F = 7.4$; df = 1, 18; $P < 0.001$).

Population trends among the most abundant species, *M. infantilis*, followed trends similar to those for all grasshoppers combined (table 30, fig. 20b).

Results from the Antelope–Sevin Spray experiment suggest that carbaryl sprays were very effective in reducing grasshopper populations. Further, the carbaryl sprays seemed to suppress second-year populations.

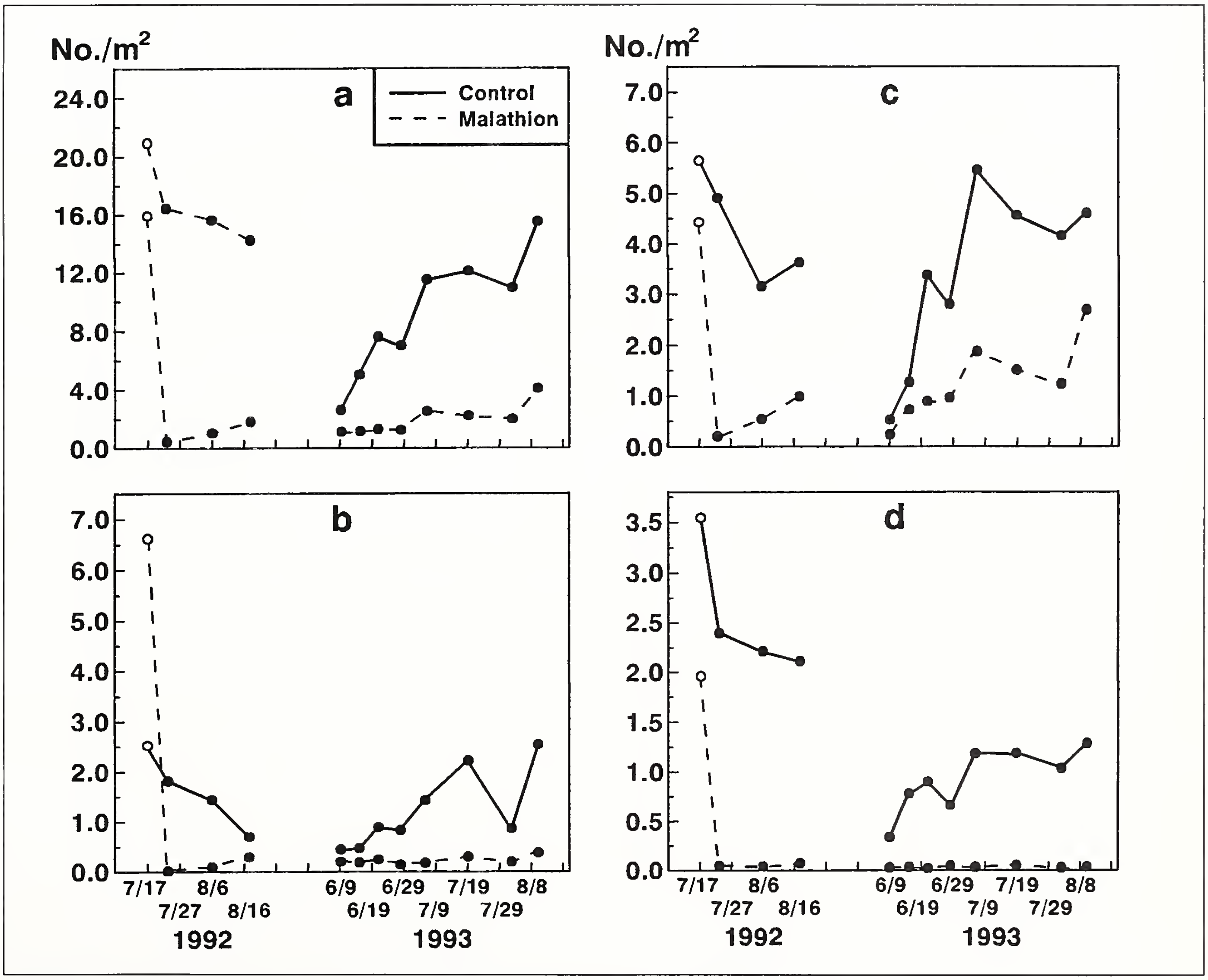

Figure 19—Population dynamics of total grasshoppers (a), *M. infantilis* (b), *M. sanguinipes* (c), and *A. deorum* (d) at the Charlie Creek block treated with standard malathion spray and control sites. The open circles represent pretreatment densities. Values indicate means. Standard errors omitted for clarity (but see table 27).

Johnson Ranch.—At the Johnson Ranch block and control sites, *M. sanguinipes* was the dominant species collected on the pretreatment sampling date, constituting 45.3 percent of grasshoppers collected at the Johnson Ranch block and 44.0 percent of grasshoppers collected at the control sites (table 31). Second and third instars constituted 69.9 percent of grasshoppers collected on the pretreatment sampling date (table 29). Adults constituted only 1.1 percent of the grasshoppers collected.

Pretreatment densities of all grasshoppers combined were quite low in the treatment block and at the control sites (3.8 ± 0.8 and 2.4 ± 0.4 per m^2, respectively) (table 32). Density of *M. sanguinipes* at the treated sites was only 1.5 ± 1.0 per m^2 on the pretreatment date. There were no significant differences between the treatment and control evaluation sites in pretreatment densities of all grasshoppers combined or *M. sanguinipes* ($P > 0.05$). The area was treated, even though initial densities were relatively low, to test a new aircraft tracking system.

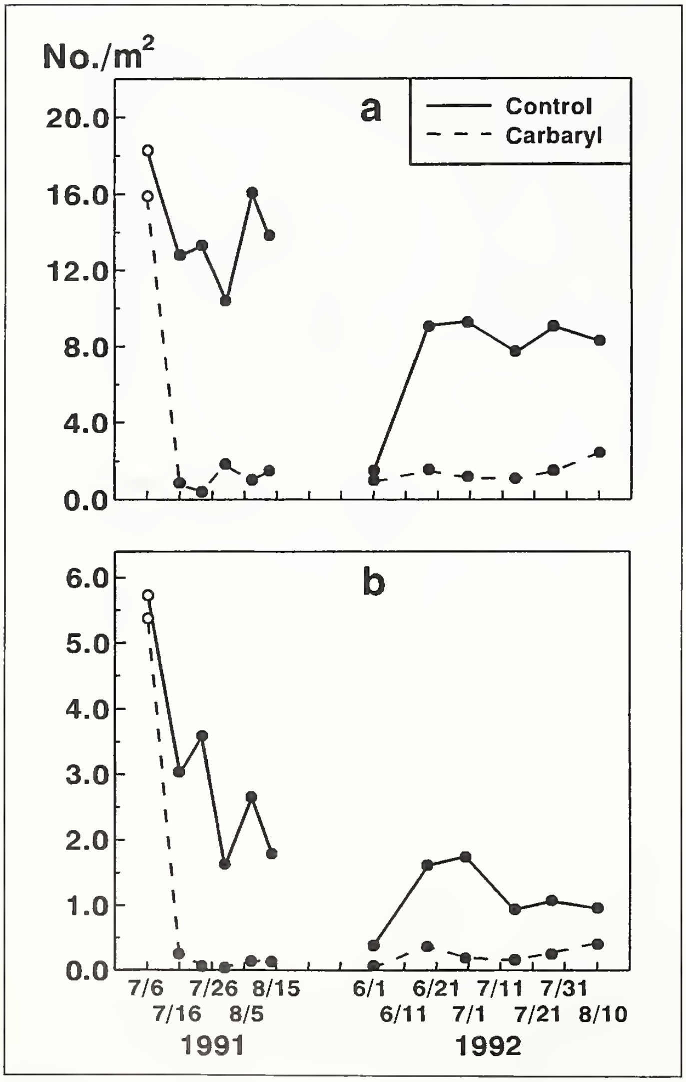

Figure 20—Population dynamics of total grasshoppers (a) and *M. infantilis* (b) at the Antelope–Sevin Spray block treated with standard carbaryl spray and control sites. The open circles represent pretreatment densities. Values indicate means. Standard errors omitted for clarity (but see table 30)

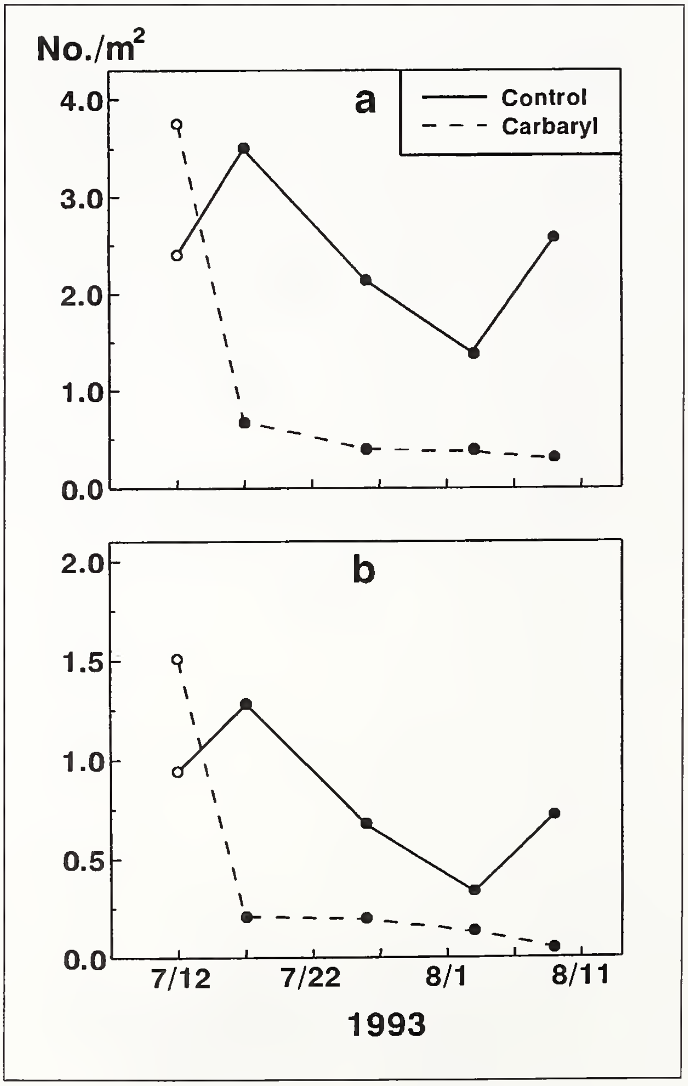

Figure 21—Population dynamics of total grasshoppers (a) and *M. sanguinipes* (b) at the Johnson Ranch block treated with standard carbaryl spray and control sites. The open circles represent pretreatment densities. Values indicate means. Standard errors omitted for clarity (but see table 32).

Total grasshoppers declined by 84.0 ± 6.4 percent immediately after treatment with carbaryl, and remained at low levels for the rest of the year (table 32, fig. 21a). Densities did not change appreciably at the control sites. Densities of *M. sanguinipes* followed similar trends (fig. 21b).

The carbaryl sprays were effective in reducing grasshopper populations. However, pretreatment grasshopper populations were not at economically damaging levels.

Hot-Spot Treatment With Malathion Sprays Study Results.—

McNany.—The two dominant species on the pretreatment date at the McNany block were *C. pellucida* and *A. elliotti*, constituting 45.5 and 27.4 percent of grasshoppers, respectively (table 33). These species constituted 50.5 percent of individuals at the control sites, as well. At the time of treatment, 93.3 percent of grasshoppers were adults (table 34).

Mean pretreatment densities of total grasshoppers were considerably higher at the malathion-treated sites than the control sites (21.2 ± 4.2 and 6.3 ± 4.9 per m^2, respectively) (table 35). Pretreatment densities of *C. pellucida* and *A. elliotti* in the treatment block were 9.2 ± 4.4 and 5.9 ± 2.0 per m^2, respectively. Their densities were under 2 per m^2 at the control sites. Pretreatment densities were significantly greater at the malathion-treated sites that control sites for total grasshoppers ($\chi^2 = 3.0$, df = 1, $P < 0.08$) and *A. elliotti* ($\chi^2 = 4.1$, df = 1, $P < 0.05$). Pretreatment densities of *C. pellucida* were not significantly different ($P > 0.05$), but this may have reflected a low sample size.

Immediately after treatment with malathion, density of total grasshoppers declined by 94.9 ± 1.9 percent in the treatment block but was not reduced at the control sites (table 35, fig. 22a). Densities remained at low levels for the rest of 1988. By June 1989 and July 1989, grasshopper populations in the treatment block declined by 49.2 ± 15.8 and 82.8 ± 6.6 percent, respectively. Mean densities increased at the control sites over the same time interval.

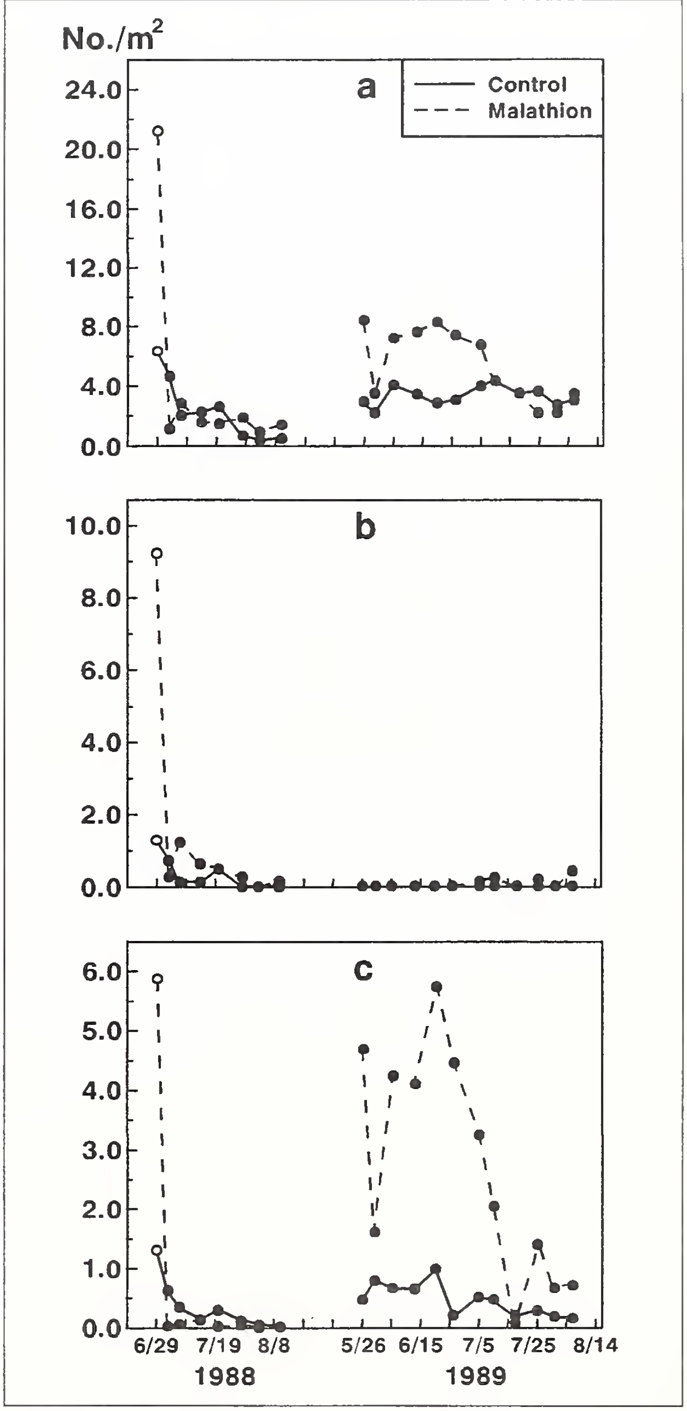

Figure 22—Population dynamics of total grasshoppers (a), *C. pellucida* (b), and *A. elliotti* (c) at the McNany block treated as a hot spot with malathion spray and control sites. The open circles represent pretreatment densities. Values indicate means. Standard errors omitted for clarity (but see table 35).

Densities of the two dominant species, *C. pellucida* and *A. elliotti*, were reduced by more than 98 percent at the treated sites but did not change appreciably at the control sites (table 35, fig. 22b,c). However, pretreatment densities of these two species at the control sites may have been too low to make accurate comparisons. Second-year densities of *C. pellucida* remained very low at the treated sites. In contrast, densities of *A. elliotti* increased to pretreatment levels a year after treatment (fig. 22c).

Results from the McNany block study suggest that the malathion hot-spot treatment was effective in reducing grasshopper populations to low levels. Application of malathion may have also reduced grasshopper populations a year after treatment, although populations of *A. elliotti* were apparently not affected. Some of the *A. elliotti* may have already laid some eggs before treatments were applied. Also, the results must be interpreted with caution because treatment sites had very different grasshopper complexes and densities than the control evaluation sites.

Blue Butte.—The three dominant species collected at the Blue Butte treatment block were *C. pellucida* (30.6 percent), *A. deorum* (28.3 percent), and *P. quadrimaculatum* (14.3 percent) (table 36). Of these species, only *A. deorum* was common at the control sites, constituting 23.9 percent of individuals. *M. infantilis*, *T. kiowa*, and *Opeia obscura* (Thomas) were also relatively abundant at the control sites. On the pretreatment date, 70.6 percent of all grasshoppers were adults (table 34).

Pretreatment densities of all grasshoppers combined at the malathion-treated sites were significantly greater than densities at the control sites (19.2 ± 2.2 and 4.2 ± 1.0 per m^2, respectively; $\chi^2 = 8.3$, df = 1, $P < 0.01$) (table 37). Mean pretreatment densities of the three dominant species were more than 2 per m^2 at the treated sites, but were less then 1 per m^2 at the control sites. Densities of *C. pellucida* at the treatment sites were significantly greater than control densities ($\chi^2 = 8.3$, df = 1, $P < 0.01$). There was no significant difference in densities of *A. deorum* or *P. quadrimaculatum* between the two sets of evaluation sites ($P > 0.05$). This finding probably reflects the small sample sizes in the study.

Immediately after treatment with malathion, total grasshopper populations decreased by 98.2 ± 4.3 percent at the treatment sites, but did not change at the control sites (table 37, fig. 23a). Densities remained low for the rest of 1989. A year later, densities rebounded to near pretreatment levels by late July. Results from repeated-measures analysis of variance indicated a significant time effect ($F = 7.5$; df = 2, 20; $P < 0.01$) and time × treatment interaction ($F = 25.7$; df = 2, 20; $P < 0.001$). Contrasts between pretreatment and posttreatment dates indicated no significant difference between average July 1990 and pretreatment densities ($P > 0.05$).

Densities of the three dominant species were reduced by more than 96 percent immediately after treatment (table 37, fig. 23b,c,d). Populations of *C. pellucida* rebounded to pretreatment levels a year after treatment, whereas populations of *A. deorum* and *P. quadrimaculatum* remained at low levels. Densities of *C. pellucida* and *P. quadrimaculatum* were too low at the control sites to assess temporal changes in untreated populations.

The results from the Blue Butte study suggested that the malathion treatment was effective in reducing populations in the year of treatment. Malathion treatment did not effectively suppress second-year populations of all grasshopper combined, although populations of *A. deorum* and *P. quadrimaculatum* were reduced a year after treatment. The efficacy data must be interpreted with caution because treated populations cannot be accurately compared with control populations; grasshopper communities at the control sites were considerably different from treatment sites.

Hovet.—The four dominant species of grasshoppers at the Hovet block were *C. pellucida* (30.8 percent), *A. elliotti* (21.3 percent), *M. infantilis* (11.5 percent) and *P. quadrimaculatum* (10.3 percent) (table 38). The last three species were also abundant at the control sites, constituting 57.0 percent of grasshoppers. *C. pellucida* was not found on the pretreatment date at the control sites. On the pretreatment date, 73.1 percent of grasshoppers were fourth or fifth instars (table 34). Pretreatment densities of total grasshoppers were quite high at the treatment (38.8 ± 9.8 per m^2) and control (25.7 ± 13.7 per m^2) sites (table 39). Mean densities of the four dominant species in the Hovet block exceeded

4 per m². Pretreatment density of *C. pellucida* was significantly greater at the treated sites than control sites ($\chi^2 = 3.7$, df = 1, $P < 0.06$). However, there was no significant difference in densities of total grasshoppers or of the other species between treatment and control sites ($P > 0.05$).

Density of total grasshoppers in the treatment block declined by 91.6 ± 2.3 percent immediately after treatment but also declined by 68.9 ± 9.8 percent at the control sites (table 39, fig. 24a). Average July 1991 densities of total grasshoppers were relatively low at the treated sites. Average second-year densities remained relatively low at the treated and control sites during July 1992. Results from repeated measures analysis of variance indicated a significant time effect ($F = 37.5$; df = 2, 16; $P < 0.001$) and time × treatment interaction ($F = 14.9$; df = 2, 16; $P < 0.001$). Contrasts between pretreatment and posttreatment densities indicated that July 1991 and July 1992 densities were significantly lower than pretreatment densities ($F = 43.9$; df = 1, 8; $P < 0.001$ and $F = 60.5$; df = 1, 8; $P < 0.001$, respectively).

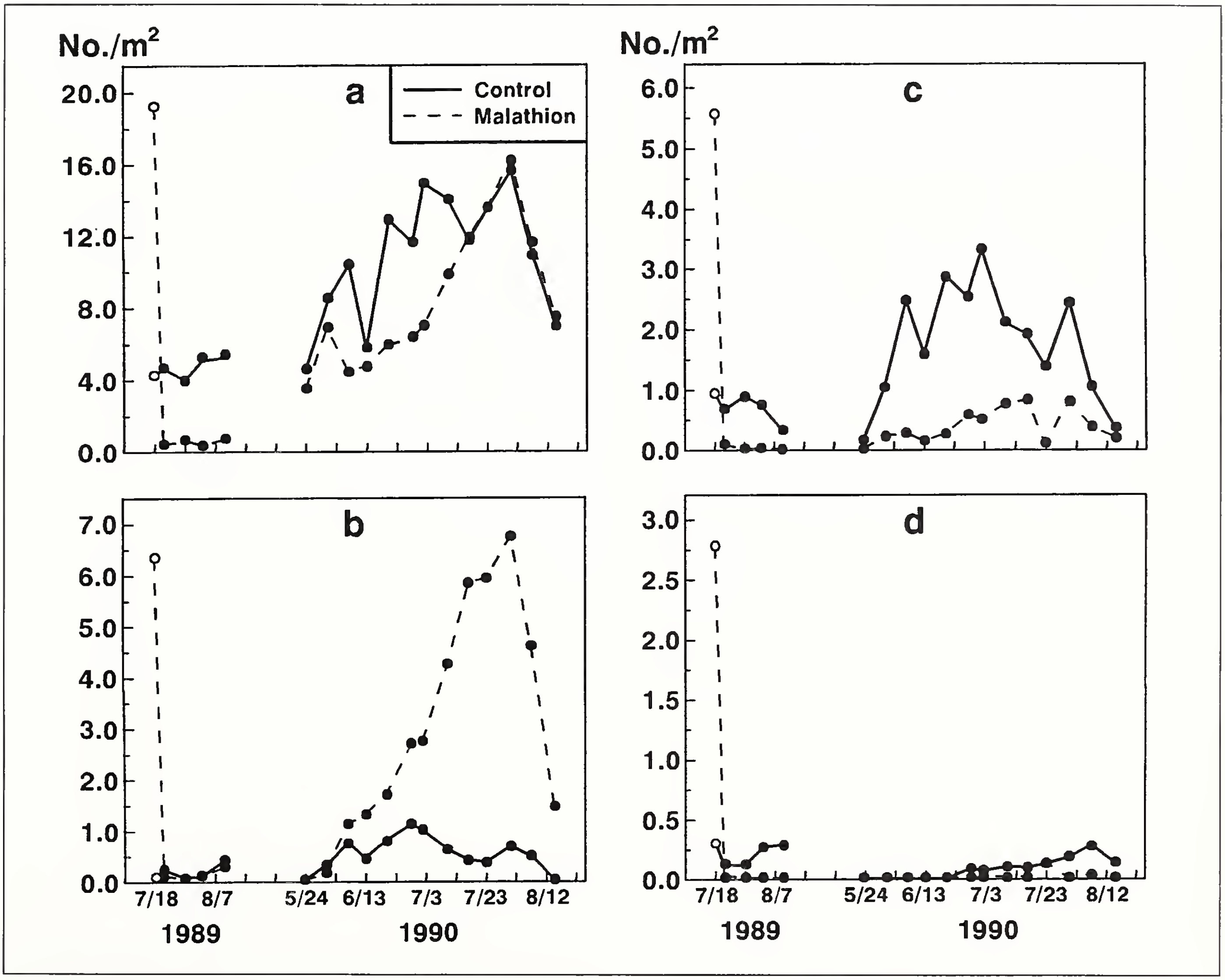

Figure 23—Population dynamics of total grasshoppers (a), *C. pellucida* (b), *A. deorum* (c), and *P. quadrimaculatum* (d) at the Blue Butte block treated as a hot spot with malathion spray and control sites. The open circles represent pretreatment densities. Values indicate means. Standard errors omitted for clarity (but see table 37).

Density of *C. pellucida* declined by 74.1 ± 13.3 percent immediately after treatment and remained at low levels throughout 1991 and 1992 (table 39, fig. 24b). Changes in populations of *C. pellucida* after treatment could not be related to temporal variation in untreated populations because this species occurred at very low levels at the control sites. Populations of *A. elliotti* (fig. 24c), *P. quadrimaculatum* (fig. 24d), and *M. infantilis* (fig. 24e) declined immediately after the treatment date at both treated and control sites. Only *P. quadrimaculatum* increased to pretreatment levels during July 1991 at the control sites. Second-year populations of *A. elliotti* remained at low levels in both treatment and control sites, whereas populations of *P. quadrimaculatum* increased slightly at the control sites compared to first year posttreatment densities. Second-year populations of *M. infantilis* increased slightly at both treatment and control sites, but densities were still below pretreatment levels.

The large reductions in grasshopper populations immediately after treatment and the large standard errors for the grasshopper estimates at the control sites suggest that the decline at the treated sites was because of malathion. However, the results also indicate that populations would have declined naturally, although not below 10 grasshoppers per m^2. It cannot be concluded that the malathion was responsible for low grasshopper densities a year after treatment because populations also declined at the control sites during 1992.

Hot-Spot Treatments With Carbaryl–Bran Bait Study Results.—

Tobacco Garden–Bait.—The Tobacco Garden–Bait block was treated initially with carbaryl–bran bait on July 10, 1990. On the first pretreatment sampling date, *C. pellucida* constituted 30.2 percent of all grasshoppers collected at the treatment sites (table 40). *M. infantilis* and *M. sanguinipes* constituted an additional 29.0 percent of grasshoppers. Although these species were also relatively abundant at the control sites, the dominant grasshopper species at these sites was the bran-rejecting species *P. quadrimaculatum*, which constituted 13.0 percent of grasshoppers (table 40). Because grasshopper densities remained high after the first treatment, the block was again treated on July 18. On the second pretreatment date (i.e., July 13, 1990), *C. pellucida*, *M. infantilis*, and *M. sanguinipes* constituted 49.4 percent of grasshoppers at the treated sites, a slightly smaller percentage than on the first pretreatment date (table 40). Twenty-three species were collected at the 10 treatment sites; 33 species were collected at the control sites. At the time of treatments, most grasshoppers were fifth instars and adults, which together constituted 65.7 percent of grasshoppers on the first pretreatment date and 80.4 percent of grasshoppers on the second pretreatment date (table 41).

Total grasshopper populations were quite high before treatment. Initial pretreatment densities at the treatment and control sites were 29.6 ± 3.6 and 12.5 ± 2.6 per m^2, respectively (table 42, fig. 25a). Pretreatment densities of total grasshopper populations at the treated and control sites were significantly different ($\chi^2 = 9.6$, df = 1, $P < 0.01$). Similarly, densities at the treated sites were significantly greater than control densities for bran acceptors ($\chi^2 = 11.2$, df = 1, $P < 0.001$), *C. pellucida* ($\chi^2 = 10.7$, df = 1, $P < 0.01$), *M. infantilis* ($\chi^2 = 3.3$, df = 1, $P < 0.07$), and *M. sanguinipes* ($\chi^2 = 5.1$, df = 1, $P < 0.05$). The majority of grasshoppers were bran-accepting species, while pretreatment densities of bran rejectors and bran-vulnerable species at the treated sites were 1.7 ± 0.3 and 3.9 ± 0.8 per m^2, respectively. Pretreatment densities of the three dominant species exceeded 3 per m^2 at the treated sites but were less than 2 per m^2 at the control sites.

Two days after the first treatment, total grasshopper density declined by 58.5 ± 8.0 percent at the treated sites; total grasshopper density did not change appreciably at the control sites (table 42, fig. 25a). After the first ground application of carbaryl–bran bait, mean density of all grasshoppers combined at the treated sites was 12.3 ± 3.0 per m^2. Densities declined again by 44.2 ± 9.2 percent after the second application of carbaryl–bran bait. Again, control populations remained fairly constant. Populations declined by a total of 75.9 ± 6.5 percent after the two applications. Densities of total grasshoppers remained relatively low throughout 1990 but increased to pretreatment levels the following year. Mean densities of all grasshoppers combined also increased slightly the following year at the control sites. Results from multivariate repeated–measures analysis of

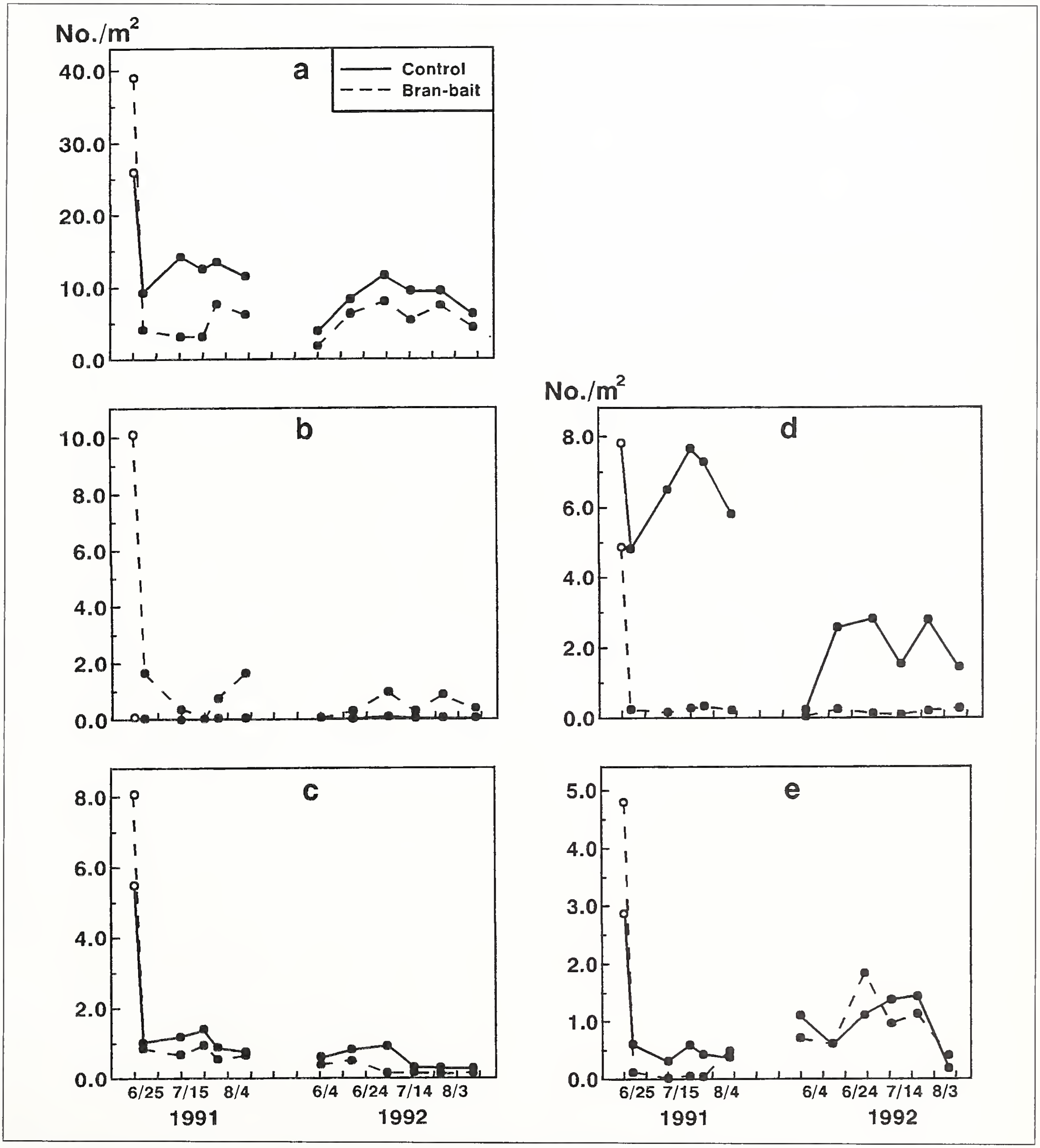

Figure 24—Population dynamics of total grasshoppers (a), *C. pellucida* (b), *A. elliotti* (c), *P. quadrimaculatum* (d), and *M. infantilis* (e) at the Hovet block treated as a hot spot with malathion spray and control sites. The open circles represent pretreatment densities. Values indicate means. Standard errors omitted for clarity (but see table 39).

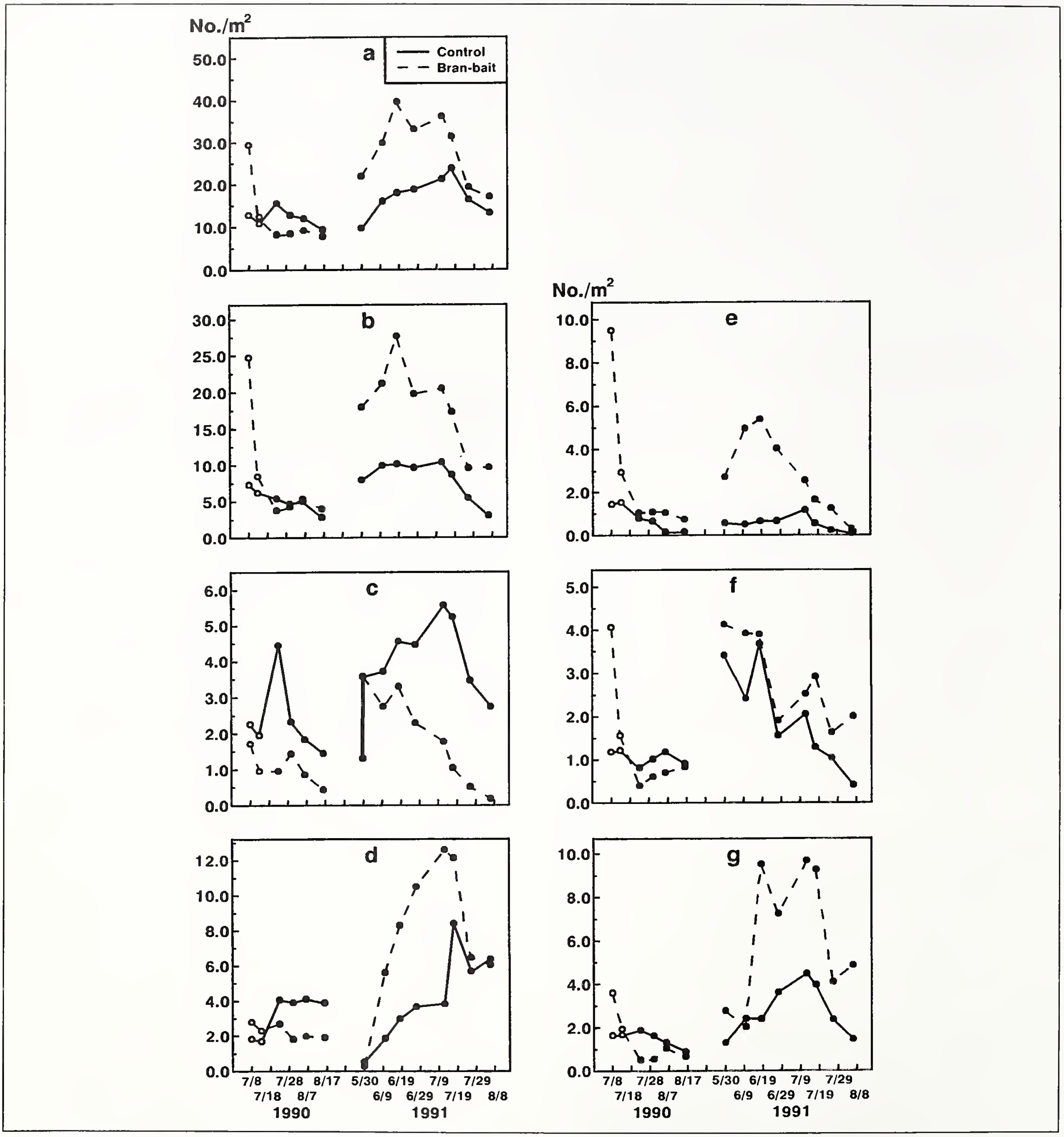

Figure 25—Population dynamics of total grasshoppers (a), bran acceptors (b), bran rejectors (c), bran vulnerable (d), *C. pellucida* (e), *M. infantilis* (f), and *M. sanguinipes* (g) at the Tobacco Garden–Bran block treated as a hot spot with carbaryl–bran bait, and control sites. The open circles represent pretreatment densities. Values indicate means. Standard errors omitted for clarity (but see table 42).

variance indicated a significant time effect ($F = 19.1$; df = 3, 16; $P < 0.001$) and time × treatment interaction ($F = 19.7$; df = 3,16; $P < 0.001$).

Populations of total bran acceptors followed similar trends as total grasshoppers at the treated and control sites (table 42, fig. 25a,b). Populations declined after treatments, remained at low levels for the rest of 1990, and rebounded to or above pretreatment levels a year after treatment. Densities of *C. pellucida*, the most common grasshopper species at the treatment sites, declined 94.3 ± 3.5 percent after two applications of carbaryl–bran bait (table 42). Second-year populations of *C. pellucida* rebounded slightly (fig. 25e).

In contrast to densities of bran-accepting species, densities of bran-vulnerable species did not change appreciably after the first or second treatment (table 42; fig. 25d). Second-year densities increased considerably at both treatment and control sites. Populations of bran rejectors did not change appreciably after treatment, and second-year densities were considerably higher than densities in 1990 (fig. 25c).

The results suggest that both applications of carbaryl–bran bait were effective in reducing grasshopper populations because the grasshoppers were predominantly bran-accepting species. Bran-vulnerable species did not seem to be affected by treatments. The data also suggest that treatments had no effect on second-year populations, although one species, *C. pellucida*, may have been suppressed by the treatments. Other species, including bran-vulnerable and bran-rejecting species, increased in the second year. The results must be interpreted with caution, however, because of the differences in grasshopper species composition and densities between the treatment and control sites.

Hay Draw.—The Hay Draw block was treated with carbaryl–bran bait twice in 1990 and once in 1991. On the initial pretreatment date in 1990, 47.0 percent of grasshoppers at the treatment sites were the bran-rejecting species *A. clavatus* (table 43). *C. pellucida* constituted another 42.6 percent of the population. These two species together constituted 88.7 percent of grasshoppers on the second pretreatment date in 1990, and 86.7 percent of grasshoppers on the pretreatment date in 1991. *A. clavatus* was similarly abundant at the control sites, as were two other species, *M. infantilis* and *M. bivitattus* (table 43). At the time of treatments in 1990, grasshopper populations were relatively young (table 41). On the first two pretreatment dates, first through fourth instars constituted 81.5 and 77.1 percent of grasshoppers, respectively. On the pretreatment date in 1991, 83.5 percent of grasshoppers were first through fourth instars. Initial pretreatment density of total grasshoppers at the carbaryl–bran bait sites was 51.3 ± 10.9 per m^2 (table 44). Density at the control sites, 8.8 ± 3.1 per m^2, was considerably lower. Similarly, densities of all bran acceptors and bran rejectors, and densities of *A. clavatus* and *C. pellucida* were much lower at control sites than at the carbaryl–bran bait sites (table 44). Approximately half of the grasshoppers were bran-accepting species (i.e., predominantly *C. pellucida*), and half were bran rejectors (i.e., predominantly *A. clavatus*).

Densities of all grasshoppers combined at the treatment and control sites did not change appreciably after the first ground application of carbaryl–bran bait (table 44). Two days after the second treatment, density of total grasshoppers at the treated sites declined by 44.2 ± 4.0 percent; density of total grasshoppers did not change at the control sites. Population reduction at the treated sites after both applications was 57.3 ± 7.9 percent. Total grasshopper populations remained fairly constant after the second treatment for the rest of 1990 (fig. 26a). A year after the initial treatment, populations of all grasshoppers combined rebounded to pretreatment levels. For example, mean change in initial pretreatment density to June 11, 1991 was only 9.6 ± 57.1 percent. After the carbaryl-bran bait application in 1991, total grasshopper densities declined by 34.3 ± 7.3 percent, but remained unchanged at the control sites over the same period. Densities remained at or below this posttreatment level for the rest of 1991. However, densities were still quite high (i.e., greater than 20 per m^2).

Populations of total bran-accepting species and *C. pellucida* followed trends similar to those for all grasshoppers combined (table 45, fig 26b,e). The initial treatment had little effect on bran acceptors or *C. pellucida*, but after the second treatment, densities declined by a total of 68.3 ± 5.3 and 75.4 ± 6.8 percent, respectively. Densities remained low for the rest of 1990, rebounded to

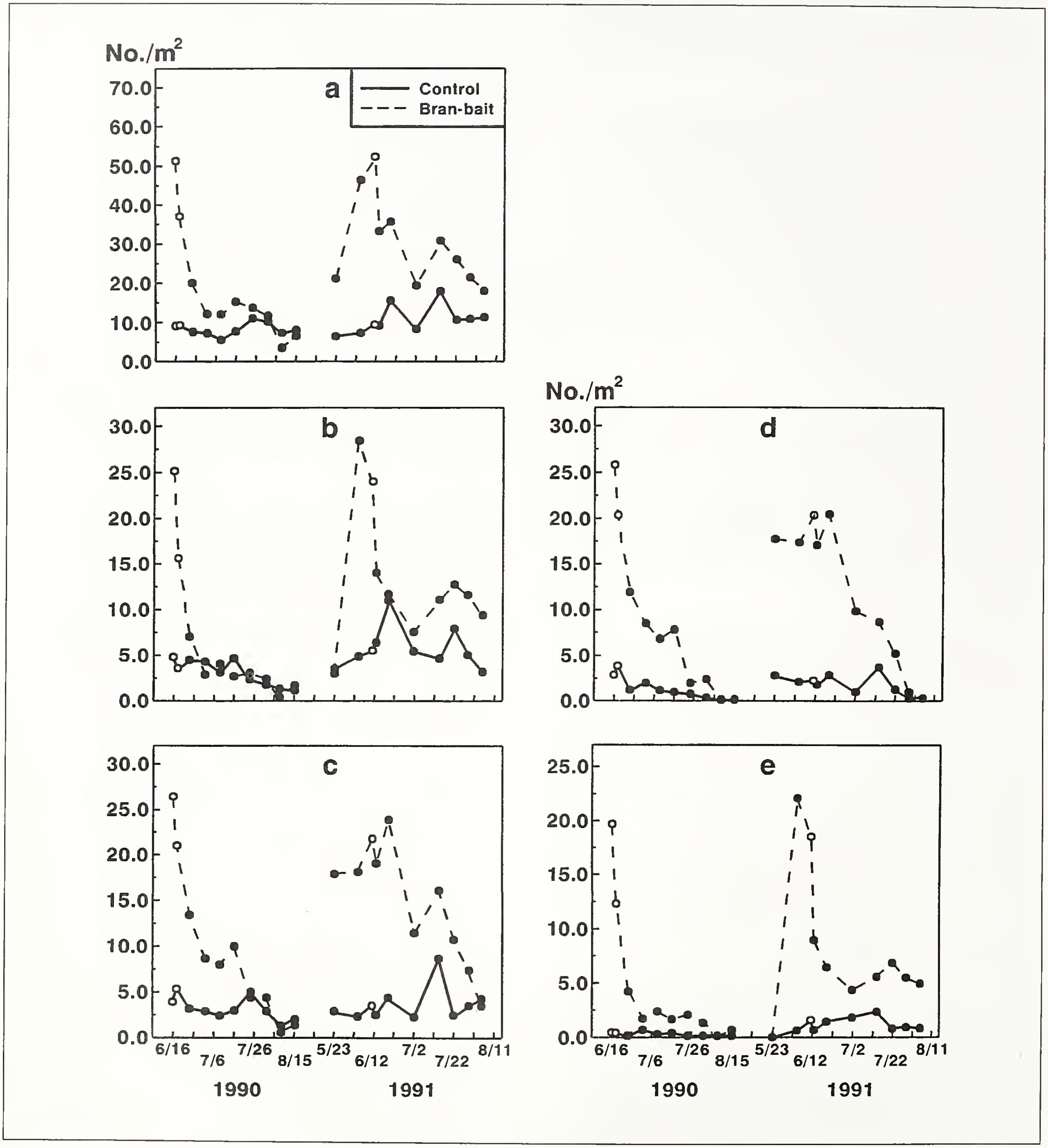

Figure 26—Population dynamics of total grasshoppers (a), bran acceptors (b), bran rejectors (c), *A. clavatus* (d), and *C. pellucida* (e) at the Hay Draw block treated as a hot spot with carbaryl–bran bait, and control sites. The open circles represent pretreatment densities. Values indicate means. Standard errors omitted for clarity (but see table 44).

pretreatment levels a year after the initial treatment, and declined moderately after the carbaryl–bran bait application in 1991.

Densities of total bran rejectors and of *A. clavatus* declined by a total of 47.8 ± 8.0 and 51.6 ± 9.3 percent, respectively, at the treated sites after the first two applications (table 44, fig. 26c,d). Populations were again quite high at the treatment sites a year after the initial treatment and did not change soon after treatment in 1991. Densities remained fairly constant at the control sites.

Treatments seemed effective in reducing grasshopper populations. However, because of the very high initial grasshopper densities, two applications were required to produce a substantial reduction in total grasshoppers. Control populations remained fairly constant throughout the study, but it is difficult to compare temporal changes at the treated sites with control sites because they had different community compositions and densities. Results should also be interpreted with caution because populations of bran rejectors declined after treatments. The high percentage of bran-rejecting species suggests that applications of carbaryl–bran bait could not be expected to be very effective against total grasshopper populations at the Hay Draw block.

Cottonwood Creek.—The Cottonwood Creek block was treated with carbaryl–bran bait twice during 1990. On the first pretreatment date, five species of grasshoppers each constituted more than 10 percent of all individuals at the treated sites; *C. pellucida* (19.9 percent), *A. clavatus* (19.0 percent), *A. deorum* (15.1 percent), *M. infantilis* (14.5 percent), and *A. elliotti* (11.9 percent) (table 45). The two dominant species at the control sites were *A. coloradus* (28.6 percent) and *A. deorum* (27.2 percent). After the initial treatment, and before the second treatment, *A. clavatus*, *C. pellucida*, *M. infantilis*, and *M. sanguinipes* constituted 77.4 percent of grasshoppers at the treated sites. Frequencies of *A. deorum* and *A. elliotti* declined substantially after the first treatment. On the first pretreatment date, 84.1 percent of grasshoppers were second through fourth instars (table 41). Only 6.6 percent of grasshoppers were adults. By the second pretreatment date, the percentage of adults increased to 20.8 percent.

Mean pretreatment densities of total grasshoppers at the treatment and control sites were 23.9 ± 5.7 and 6.2 ± 1.3 per m^2, respectively (table 46). Densities of bran acceptors and bran rejectors in the treatment block were 16.6 ± 4.0 and 7.3 ± 2.7 per m^2, respectively. Densities of the five dominant species at the treatment sites exceeded 2 per m^2. In contrast, densities of the individual species (except for densities of *A. deorum)* at the control sites were less than 1 per m^2. Densities at the control sites were significantly lower than at the treated sites for total grasshoppers ($\chi^2 = 7.4$, df = 1, $P < 0.01$), bran acceptors ($\chi^2 = 5.8$, df = 1, $P < 0.05$), *C. pellucida* ($\chi^2 = 8.6$, df = 1, $P < 0.01$), *M. infantilis* ($\chi^2 = 3.1$, df = 1, $P < 0.08$), and *A. elliotti* ($\chi^2 = 4.4$, df = 1, $P < 0.05$).

Two days after the first treatment, densities of total grasshoppers at the treated sites declined by 69.0 ± 4.1 percent (table 46, fig. 27a). Densities declined slightly by a mean 22.6 ± 7.4 percent after the second treatment. Populations did not change appreciably at the control sites over the same time interval. Densities of total grasshoppers remained relatively low for the rest of 1990. Second-year populations were also substantially lower than the pretreatment populations at the treated sites, while densities at the control sites remained fairly constant. Results from repeated measures analysis of variance of pretreatment and posttreatment densities of total grasshoppers indicated a significant time effect ($F = 10.9$; df = 3, 30; $P < 0.001$) and time × treatment interaction ($F = 13.6$; df = 3, 30; $P < 0.001$). Contrasts between pretreatment and posttreatment densities indicated that June and July 1991 densities were significantly lower than pretreatment densities ($F = 29.7$; df = 1, 10; $P < 0.001$, and $F = 9.8$; df = 1, 10; $P < 0.01$, respectively).

Trends in populations of total bran acceptors and of the bran-accepting species *C. pellucida*, *A. deorum*, *M. infantilis*, and *A. elliotti* were similar to population trends for all grasshoppers combined (table 46; fig. 27b,d,f,g,h). Densities of these individual species declined by more than 76 percent after two applications of carbaryl–bran bait, while populations at the control sites remained relatively constant.

Densities of all bran-rejecting grasshoppers combined declined by a mean 43.3 ± 17.9 percent at the treated

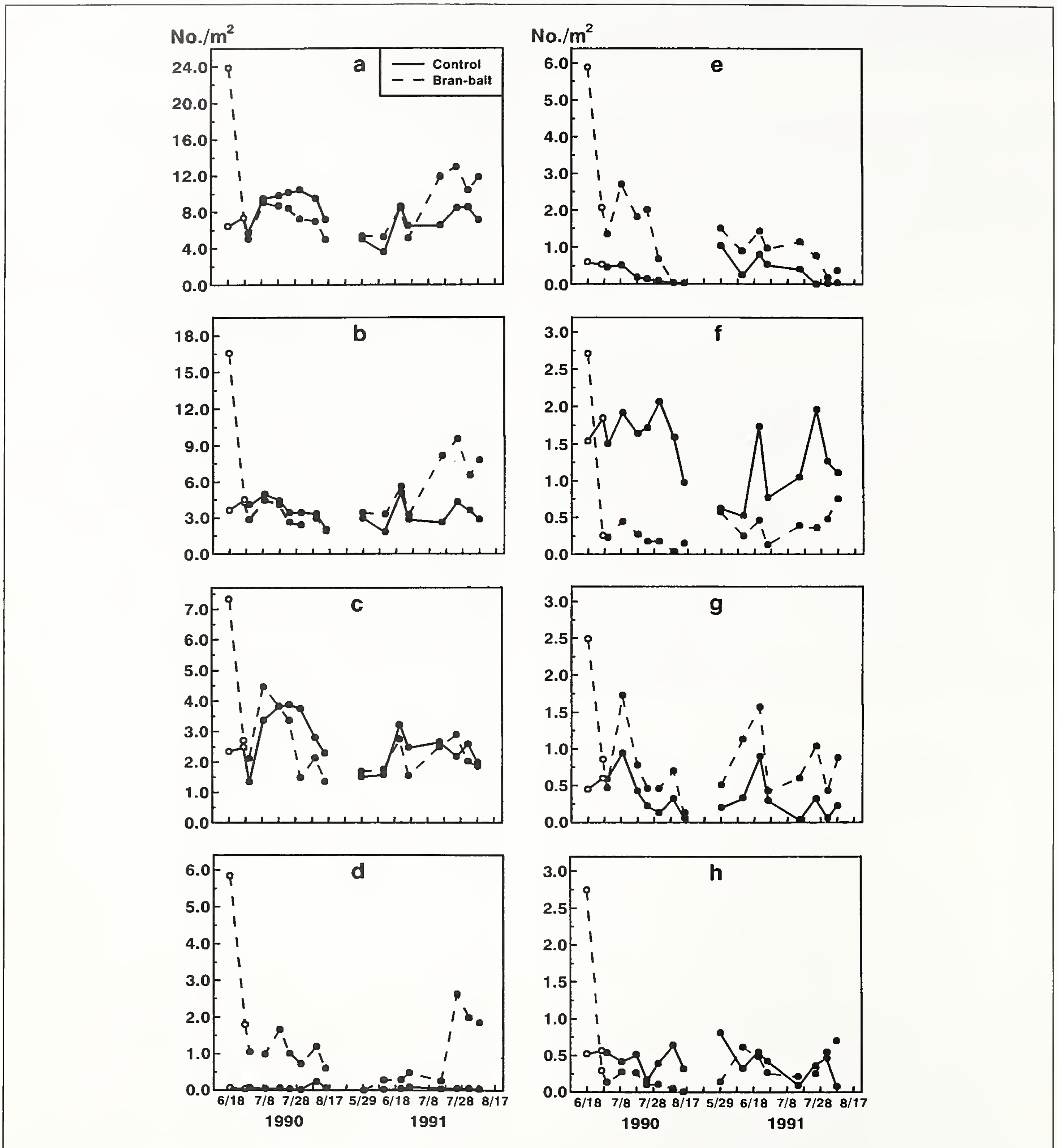

Figure 27—Population dynamics of total grasshoppers (a), bran acceptors (b), bran rejectors (c), *C. pellucida* (d), *A. clavatus* (e), *A. deorum* (f), *M. infantilis* (g), and *A. elliotti* (h) at the Cottonwood Creek block treated as a hot spot with carbaryl–bran bait and control sites. The open circles represent pretreatment densities. Values indicate means. Standard errors omitted for clarity (but see table 46).

sites after two applications of carbaryl–bran bait (table 46, fig. 27c). However, populations declined similarly at the control sites. Densities remained relatively low a year after treatment. Although the mean density of the bran-rejecting species *A. clavatus* decreased appreciably after the first treatment (fig. 27e), population responses were highly variable between treated sites and overall change in the population was not significant (table 46).

Results from the Cottonwood Creek study suggest that ground application of carbaryl–bran bait was effective in reducing grasshopper populations to relatively low levels, in part because of the high proportion of bran-accepting species in the treatment block. Further, most of the reduction occurred after the first application. The second-year reduction in grasshopper populations cannot necessarily be attributed to the effects of treatments because populations of bran rejectors were also reduced. Also, accurate comparisons of grasshopper population at the treated and control sites are difficult to make because grasshopper composition and densities were very different at the two sets of blocks.

Antelope Creek.—The Antelope Creek block was treated with carbaryl–bran bait twice in 1990. On the first pretreatment date, 83.1 percent of grasshoppers at the treatment sites were *M. infantilis* (table 47). *M. infantilis* constituted 51.5 percent of all grasshoppers at the treatment sites on the second pretreatment date, and *Encoptolophus costalis* (Scudder) and *P. nebrascensis* were also abundant (18.8 and 12.7 percent, respectively). At the control sites, *M. infantilis* was also the dominant species, constituting 65.7 and 44.5 percent of individuals collected on the first and second pretreatment dates, respectively. On the first pretreatment date, 77.9 percent of grasshoppers were third and fourth instars; only 1.8 percent were adults (table 41). In contrast, on the second pretreatment date, 11.7 percent of grasshoppers were adults.

The initial pretreatment densities of grasshoppers at the treatment and control sites were 50.9 ± 12.6 and 5.7 ± 1.7 per m^2, respectively (table 48). Bran-accepting species (predominantly *M. infantilis)* constituted most of the grasshoppers; the mean density of bran rejectors at the treatment sites was only 1.7 ± 0.5 per m^2. Pretreatment densities of total grasshoppers, bran acceptors, bran rejectors, and *M. infantilis* were considerably lower at the control sites than at the treated sites.

Two days after the first treatment with carbaryl–bran bait, total grasshopper density declined by 57.2 ± 6.5 percent (table 48, fig. 28a). After the second treatment, total grasshopper density declined by 42.6 ± 7.8 percent. The reduction in the total grasshopper population after both treatments was 81.4 ± 4.8 percent. Populations at the treated sites remained at relatively low levels for the rest of 1990 and were still much lower than the initial pretreatment levels a year after treatment. At the control sites, densities of total grasshoppers were relatively constant throughout 1990 and 1991 (table 48, fig. 28a).

Populations of bran-accepting species and *M. infantilis* followed trends similar to those for all grasshoppers combined (table 48, fig. 28b,d). Densities of bran-rejecting species did not change appreciably after the first treatment at either the treatment or control sites (table 48, fig. 28c). Densities did decline at the treatment sites after the second treatment, but densities also declined at control sites. Second-year densities of bran rejectors at the treatment sites were similar to pretreatment densities.

The results suggest that carbaryl–bran bait was effective in reducing populations of grasshoppers because of the high proportion of bran-accepting species. Second-year populations were also much lower than the initial pretreatment levels, although final density at the treatment sites did increase to more than 20 grasshoppers per m^2. Again, the results must be interpreted with caution because of the large differences in initial grasshopper densities at the treatment and control sites.

Cottonwood Creek II.—The dominant species of grasshoppers at the Cottonwood Creek II treatment block and control sites were *M. infantilis* and *A. deorum.* These species together constituted 60.6 and 50.4 percent of grasshoppers at the treatment and control sites, respectively (table 49). On the pretreatment date, grasshopper populations were fairly young: 81.9 percent of grasshoppers were first through third instars (table 41).

Pretreatment densities of total grasshoppers at the treated and control sites were 13.4 ± 2.6 and 8.0 ± 2.2 per m^2, respectively (table 50). Pretreatment densities of bran-accepting and bran-rejecting species at the treated sites were 11.2 ± 2.3 per m^2 and 2.0 ± 0.6 per m^2, respectively. Densities of the two dominant species at the treated sites exceeded 2 per m^2.

Three days after treatment with carbaryl–bran bait, total grasshopper densities declined by 52.3 ± 7.6 percent at the treated sites; densities did not change appreciably at the control sites (table 50, fig. 29a). Densities at the treated sites remained relatively low for the rest of 1991; however, populations rebounded to or above pretreatment levels a year after treatment.

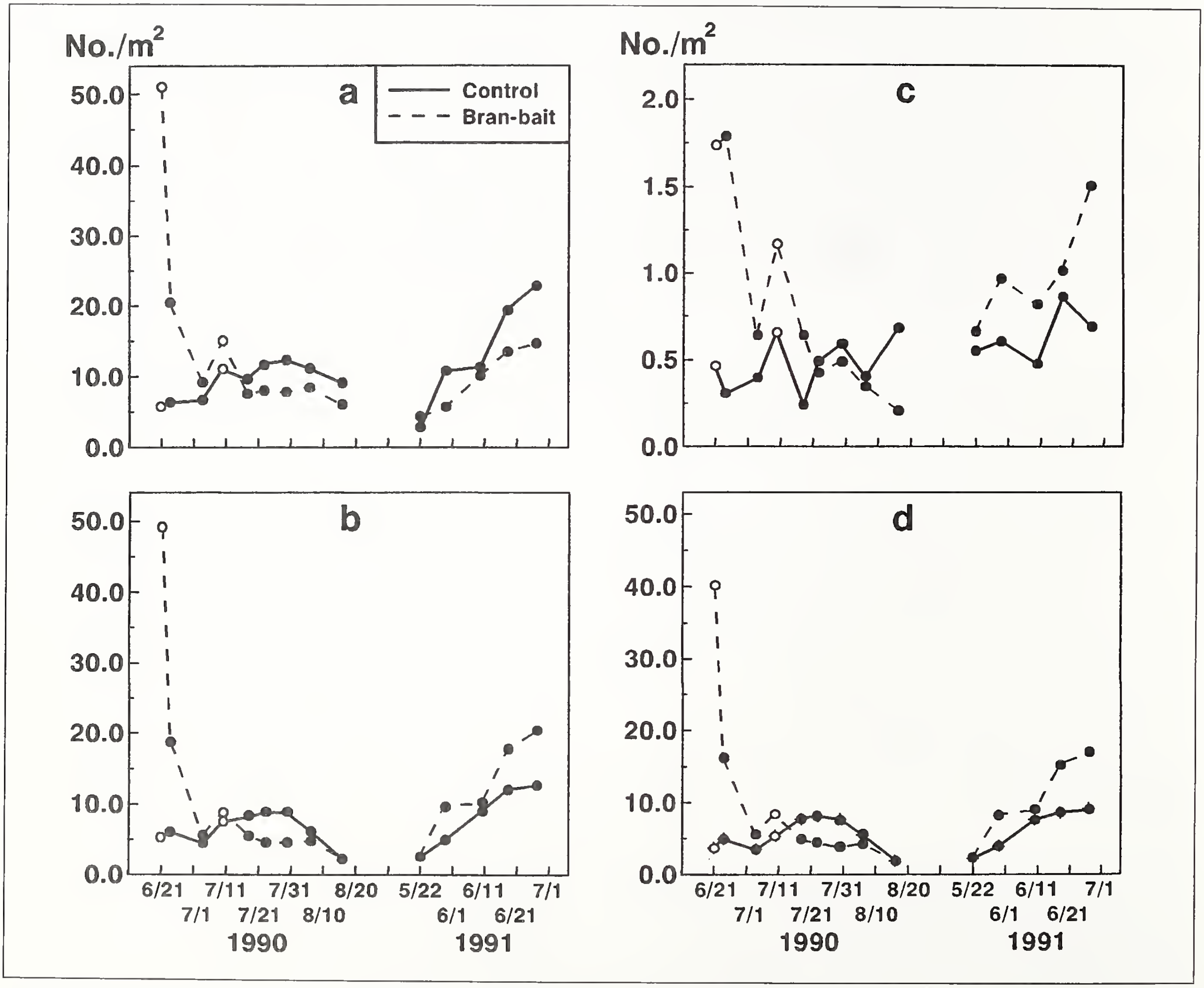

Figure 28—Population dynamics of total grasshoppers (a), bran acceptors (b), bran rejectors (c), and *M. infantilis* (d) at the Antelope Creek block treated as a hot spot with carbaryl–bran bait and control sites. The open circles represent pretreatment densities. Values indicate means. Standard errors omitted for clarity (but see table 48).

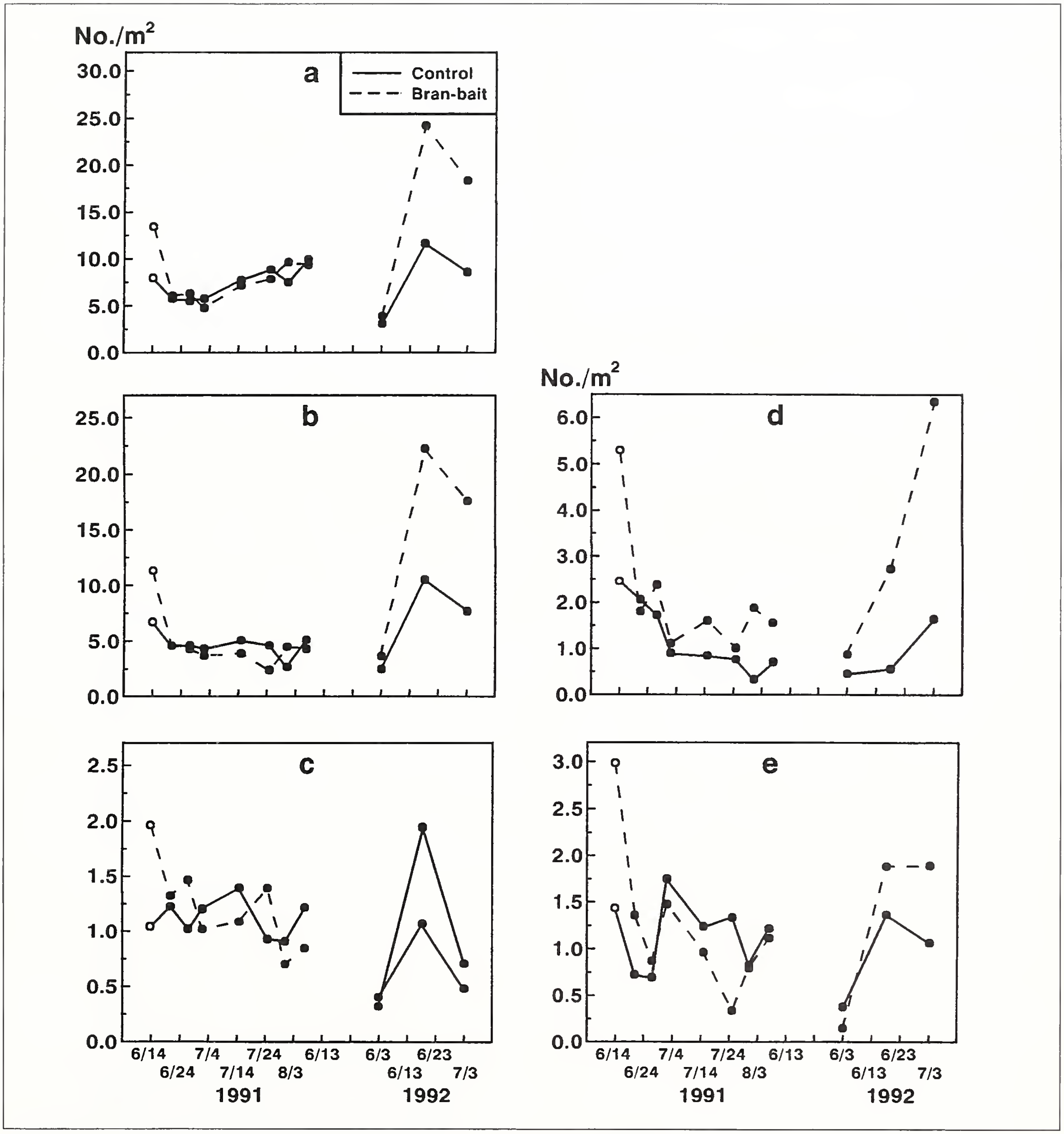

Figure 29—Population dynamics of total grasshoppers (a), bran acceptors (b), bran rejectors (c), *M. infantilis* (d), and *A. deorum* (e) at the Cottonwood Creek II block treated as a hot spot with carbaryl–bran bait and control sites. The open circles represent pretreatment densities. Values indicate means. Standard errors omitted for clarity (but see table 50).

Populations of all bran-accepting species combined, *M. infantilis*, and *A. deorum* followed trends similar to those for all grasshoppers combined (table 50, fig. 29b,d,e). In contrast, populations of bran rejectors did not change appreciably in 1990 and 1991 (fig. 29c).

The results from the Cottonwood Creek II study suggest that the ground application of carbaryl–bran bait was effective in reducing grasshopper populations, in part because of the large proportion of bran-accepting species in the treated area. However, ground applications of carbaryl–bran bait had no apparent effect on second-year populations.

Schapers.—The dominant species at the Schapers block treatment sites, constituting 53.8 and 28.7 percent of all grasshoppers, respectively, were *A. elliotti* and *C. pellucida* (table 51). At the control sites, *A. elliotti* constituted only 2.7 percent of grasshoppers; dominant species at the control sites were *M. sanguinipes* (37.3 percent), *M. infantilis* (12.8 percent), and *C. pellucida* (12.4 percent). On the pretreatment date, 95.3 percent of grasshoppers were third through fifth instars (table 41).

Pretreatment densities of all grasshoppers combined were much higher at the treatment sites than control sites (43.6 ± 8.4 *versus* 8.3 ± 2.2 per m^2, respectively) (table 52, fig. 30a). Most of these grasshoppers at the treatment sites were bran-accepting species; the mean density of bran rejectors was only 1.6 ± 1.2 per m^2. Densities of the two dominant species were more than 12 per m^2 at the treatment sites but below 1 per m^2 at the control sites.

Two days after treatment with carbaryl–bran bait, densities of total grasshoppers at the treatment sites declined by 68.5 ± 7.5 percent to a density of 11.9 ± 2.0 per m^2 (table 52, fig. 30a). Densities also declined by a mean 32.9 ± 9.6 percent at the control sites. Populations of total grasshoppers remained low for the rest of 1991 and throughout 1992. Densities were fairly constant at the control sites.

Populations of all bran acceptors combined, *A. elliotti*, and *C. pellucida* followed patterns similar to those for total grasshoppers (table 52; fig. 30b,d,e). Their densities declined by more than 53 percent immediately after treatment and remained at low levels throughout 1991 and 1992. In contrast, densities of bran rejectors were generally close to pretreatment levels at the treatment and control sites (table 52, fig. 30c).

The results from the Schapers block study suggest that ground application of carbaryl–bran bait was very effective in immediately reducing populations of grasshoppers, in part because of the high proportion of bran-accepting species. The treatment may also have suppressed populations a year after treatment. Because of the differences in grasshopper species composition and densities between the treatment and control sites, however, it is difficult to make accurate comparisons.

Extended Swath-Width Study Results.—

Mead.—*M. sanguinipes*, *M. infantilis*, *M. packardii*, and *A. deorum* were dominant species of grasshoppers at the Mead study sites, together constituting 77.0 percent of all grasshoppers in the 13.7-m swath-width block, 81.2 percent of grasshoppers in the extended swath-width block, and 70.8 percent of grasshoppers at the control sites (table 53). On the pretreatment date, 83.0 percent of grasshoppers at the treatment and control sites were third through fifth instars; only 7.6 percent were adults (table 54).

Mean pretreatment densities at the 13.7-m swath-width block, the 27.4-m swath-width blocks, and the control sites were 18.8 ± 5.5, 11.5 ± 1.9, and 10.0 ± 1.9 per m^2, respectively (table 55). Most were bran-accepting species, whereas densities of bran rejectors and bran-vulnerable species were under 2 per m^2 at the three sets of evaluation sites. Densities of *M. sanguinipes* and *M. packardii* were more than 2 per m^2 at the 13.7-m swath-width block. Densities of *M. sanguinipes* and *M. infantilis*, the two dominant species at the 27.4-m swath-width block, exceeded 2 per m^2. There were no significant differences in pretreatment densities between the treatment blocks and control sites for total grasshoppers, bran acceptors, bran rejectors, bran-vulnerable species, *M. sanguinipes*, *M. infantilis*, or *A. deorum* ($P > 0.05$). Densities of *M. packardii* were significantly greater at the treated sites than control sites ($\chi^2 = 4.5$, df = 1, $P < 0.05$).

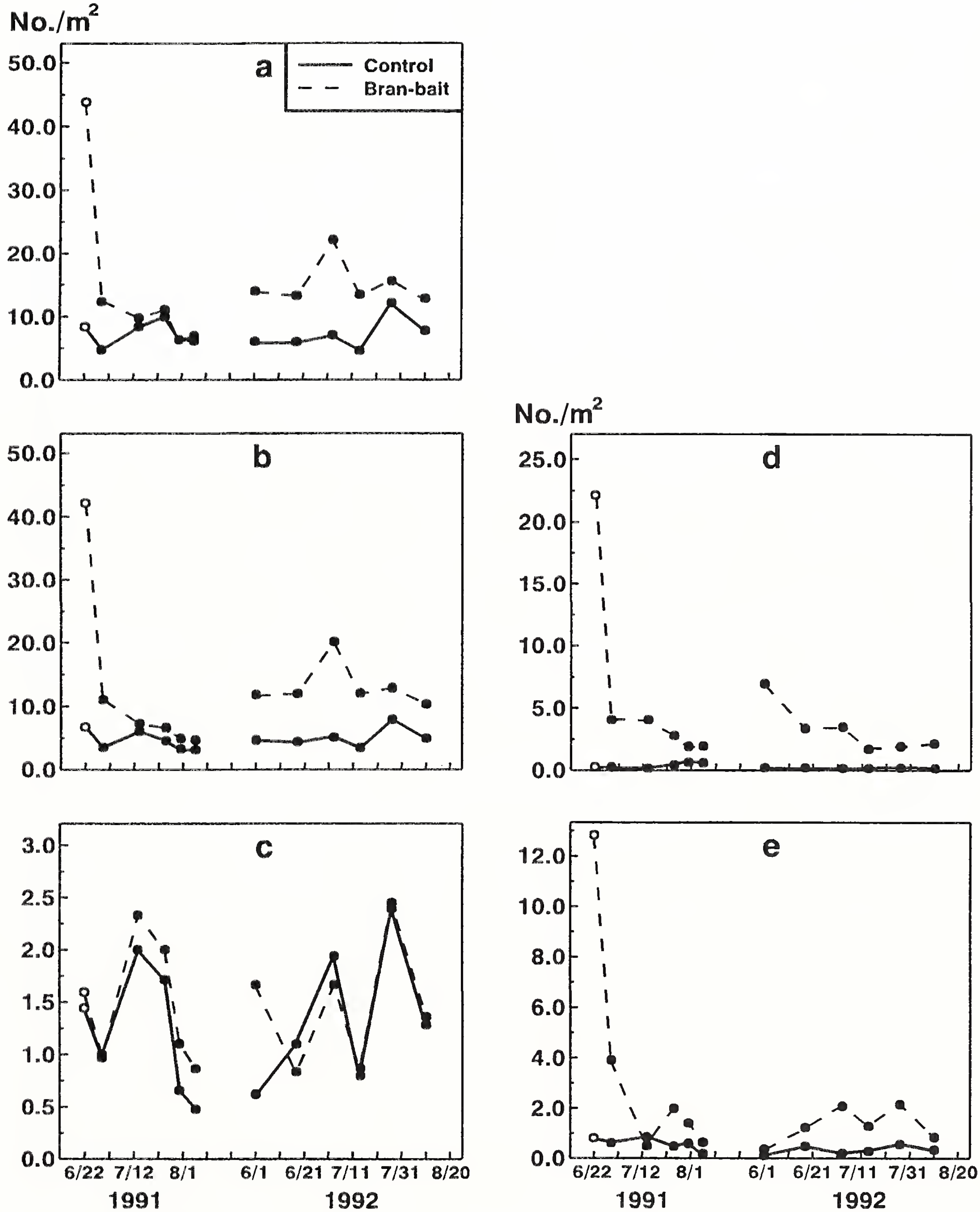

Figure 30—Population dynamics of total grasshoppers (a), bran acceptors (b), bran rejectors (c), *A. elliotti* (d), and *C. pellucida* (e) at the Schapers block treated as a hot spot with carbaryl–bran bait, and control sites. The open circles represent pretreatment densities. Values indicate means. Standard errors omitted for clarity (but see table 52).

Three days after application of carbaryl–bran bait, total grasshopper densities declined by 51.7 ± 7.8 and 40.0 ± 10.0 percent at the 13.7-m and 27.4-m swath-width blocks, respectively (table 55, fig. 31a). Density did not change appreciably at the control sites. Within 9 days of treatment, densities of total grasshoppers increased slightly in the 27.4-m swath-width block and remained relatively low in the 13.7-m swath-width block.

The populations of all bran-acceptors combined followed trends similar to those for all grasshoppers combined (table 55, fig. 31b). Densities of *M. sanguinipes*, the dominant species in the 13.7-m swath-width block, declined by 72.3 ± 9.9 percent in that block but did not decline in the 27.4-m swath-width block or at the control sites (table 56, fig. 31e). In contrast, densities of *M. infantilis*, the dominant species in the 27.4-m swath-width block, declined by 57.6 ± 7.9 percent in that block, but did not decline in the 13.7-m swath-width block or at control sites (table 55, fig. 31f). Densities of *M. packardii* declined in the 13.7-m swath-width block immediately after treatment but soon increased to pretreatment levels (table 55, fig. 31g). Densities of *A. deorum* declined in the 27.4-m swath-width block immediately after treatment but soon increased to near pretreatment levels (fig. 31h).

Populations of bran-rejecting (Fig. 31c) and bran-vulnerable species (fig. 31d) were not reduced appreciably in the treatment blocks.

Results from the Mead study suggest that aerial application of carbaryl–bran bait with the standard 14.7-m swath-width was more effective in reducing grasshopper populations than the extended swath width. However, these results may have been influenced by heavy rains that occurred at the time of treatments.

Crighton.—In the 13.7-m swath-width block, the dominant species of grasshoppers were *P. quadrimaculatum* (23.6 percent), *M. infantilis* (15.3 percent), *M. sanguinipes* (14.6 percent), and *A. elliotti* (14.5 percent) (table 56). In the 27.4-m swath-width block, *M. sanguinipes*, *C. pellucida*, and *A. clavatus* were the dominant species, constituting 25.1, 23.1, and 10.5 percent of grasshoppers, respectively. Dominant species at the control sites were *M. sanguinipes* (22.2 percent), *M. infantilis* (16.8 percent), *P. quadrimaculatum* (13.9 percent), and *A. deorum* (10.6 percent). On the pretreatment dates, most grasshoppers were fourth and fifth instars (table 54). Adults constituted only 7.6 percent of the population.

At the 13.7-m and 27.4-m swath-width blocks, pretreatment densities were similar (20.9 ± 2.5 and 21.7 ± 5.0 per m^2, respectively) (table 57). In contrast, mean pretreatment density at the control sites was only 7.4 ± 2.0 per m^2. At the 13.7-m and 27.4-m swath-width blocks, pretreatment densities of bran acceptors were 12.1 ± 3.2 and 14.1 ± 4.0 per m^2, respectively. Bran rejectors were also abundant at the two blocks, with pretreatment densities of 8.1 ± 2.0 and 5.4 ± 1.6 per m^2, respectively.

Four species of grasshoppers had pretreatment densities exceeding 2 per m^2 at the 13.7-m swath-width block. Three species had similar pretreatment densities at the 27.4-m swath-width block. At the control sites, mean densities of all individual species were under 2 per m^2.

Pretreatment densities at the control sites were significantly less than densities at the two bait treatment blocks for total grasshoppers ($\chi^2 = 13.2$, df = 1, $P < 0.001$), bran acceptors ($\chi^2 = 5.9$, df = 1, $P < 0.05$), bran rejectors ($\chi^2 = 8.2$, df = 1, $P < 0.01$), bran-vulnerable species ($\chi^2 = 3.4$, df = 1, $P < 0.07$), *M. sanguinipes* ($\chi^2 = 7.4$, df = 1, $P < 0.01$), *C. pellucida* ($\chi^2 = 3.7$, df = 1, $P < 0.06$), *A. elliotti* ($\chi^2 = 6.8$, df = 1, $P < 0.01$), and *A. clavatus* ($\chi^2 = 5.5$, df = 1, $P < 0.05$). Only control densities of *M. infantilis* and *P. quadrimaculatum* were not significantly different from treatment densities ($P > 0.05$).

In the 27.4-m swath-width block, total grasshopper density declined by 61.9 ± 11.7 percent 2 days after treatment with carbaryl–bran bait, and remained relatively low throughout July (table 57, fig. 32a). Posttreatment grasshopper density in this block was under 10 per m^2. In contrast, densities did not change appreciably in the 13.7-m swath-width block or at the control sites.

Populations of all bran-accepting species combined followed trends similar to those for total grasshoppers, except that densities declined slightly in the 13.7-m swath-width block (table 57, fig. 32b). Individual bran-

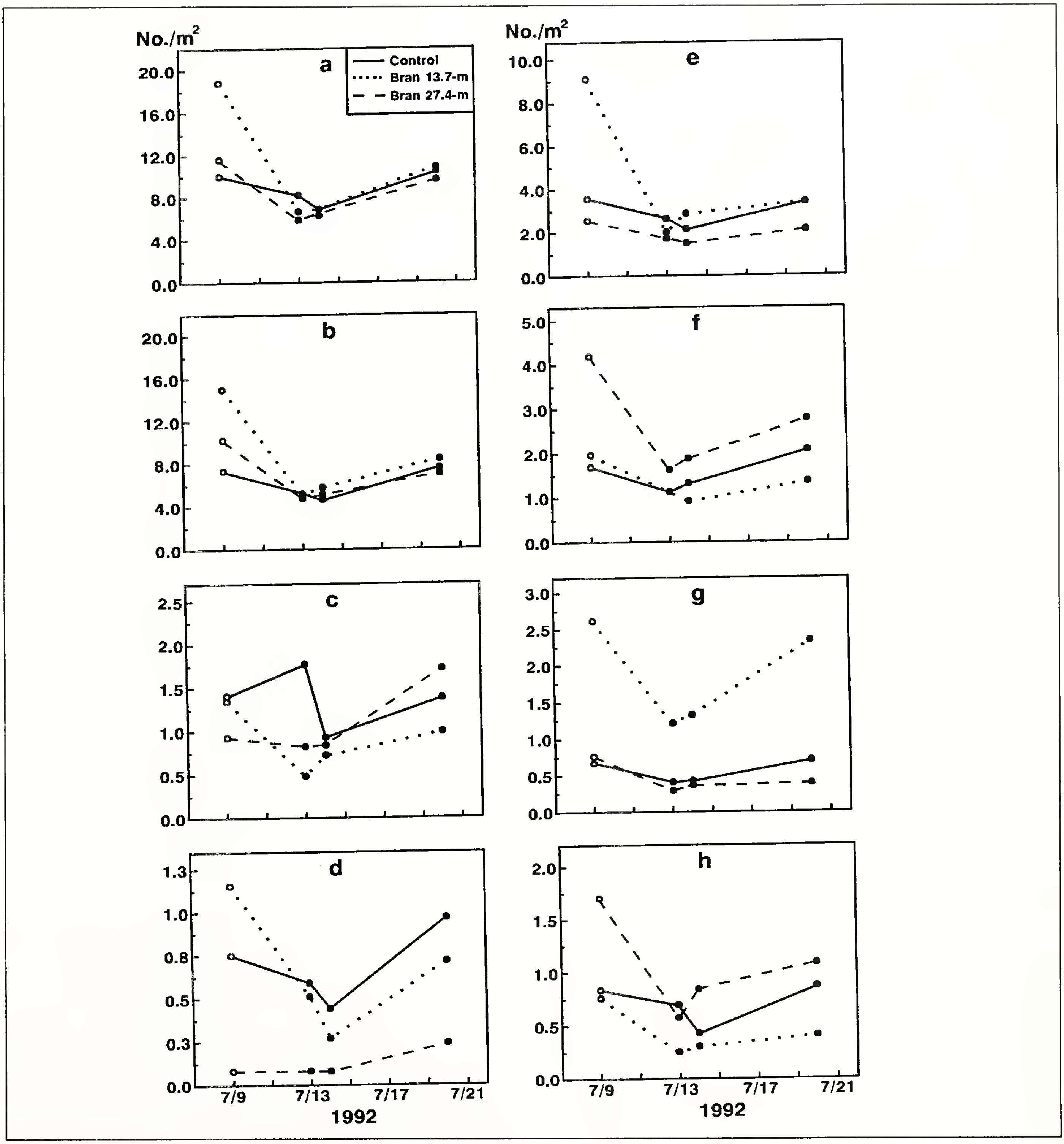

Figure 31—Population dynamics of total grasshoppers (a), bran acceptors (b), bran rejectors (c), bran vulnerable (d), *M. sanguinipes* (e), *M. infantilis* (f), *M. packardii* (g), and *A. deorum* (h) at the Mead block treated with aerial applications of carbaryl–bran bait using a standard and extended swath width and control sites. The open circles represent pretreatment densities. Values indicate means. Standard errors omitted for clarity (but see table 55).

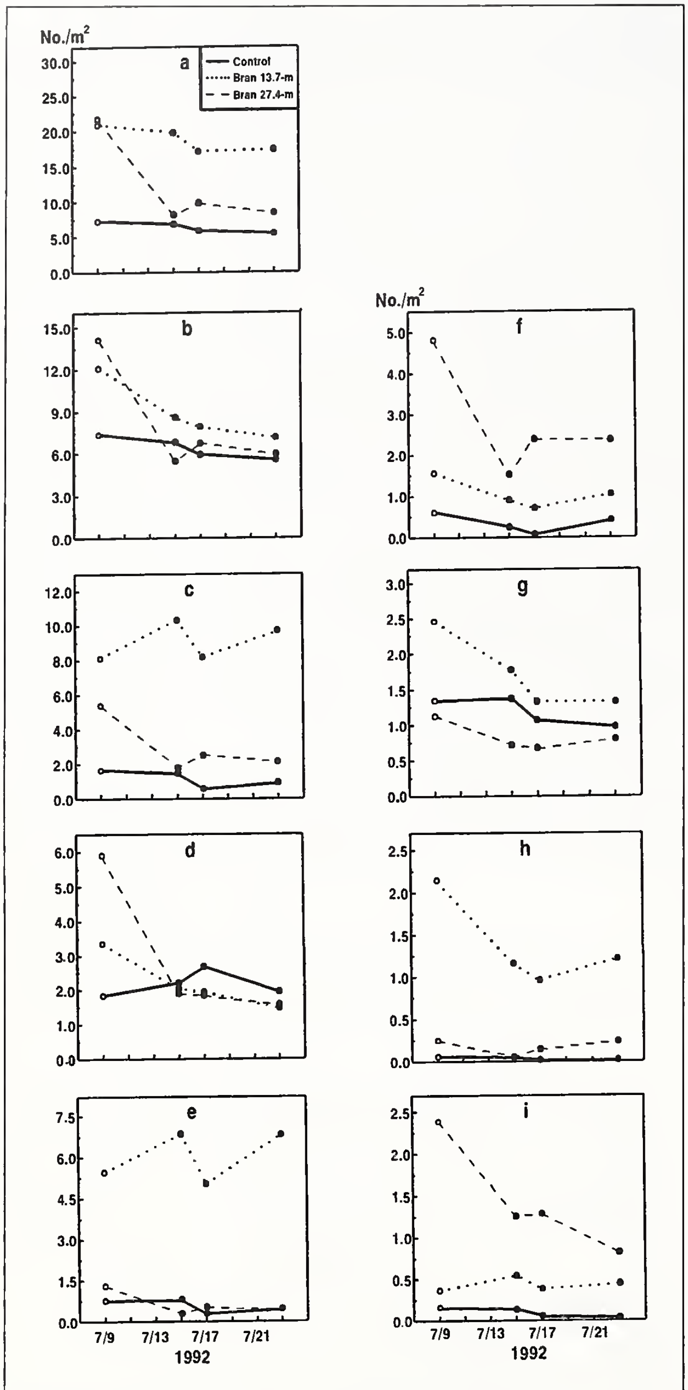

Figure 32—Population dynamics of total grasshoppers (a), bran acceptors (b), bran rejectors (c), *M. sanguinipes* (d), *P. quadrimaculatum* (e), *C. pellucida* (f), *M. infantilis* (g), *A. elliotti* (h), and *A. clavatus* (i) at the Crighton block treated with aerial applications of carbaryl–bran bait using a standard and extended swath width and control sites. The open circles represent pretreatment densities. Values indicate means. Standard errors omitted for clarity (but see table 57).

accepting species responded differently to treatments (table 57). Densities of *M. sanguinipes*, the only species abundant at both treatment blocks, declined in both blocks and did not change at the control sites (fig. 32d). Mean densities of *C. pellucida*, a dominant species in the 27.4-m swath-width block, declined in both treatment blocks (fig. 32f). However, the very large standard errors associated with percentage change estimates indicate that populations of *C. pellucida* were not reduced at some evaluation sites within the treatment blocks. *C. pellucida* populations were too low at the control sites to evaluate temporal changes in untreated populations of the species. Populations of *M. infantilis* and *P. quadrimaculatum* did not change appreciably in either treatment block (fig. 32e,g). Similarly, populations of *A. elliotti* did not change in the 13.7-m swath-width block (fig. 32h). This species was not abundant at the 27.4-m swath-width or control sites.

Populations of all bran-rejectors combined declined by 69.6 ± 7.5 percent in the 27.4-m swath-width block, reflecting changes mainly in populations of *A. clavatus* (table 57, fig. 32c,i). Populations of these grasshoppers did not change appreciably after treatment with carbaryl-bran bait in the 13.7-m swath-width block or at control sites.

The results from the Crighton block study were inconclusive. Densities of total grasshoppers, total bran acceptors, and *M. sanguinipes* declined at sites treated with carbaryl-bran bait using the extended swath width, but so did densities of total bran-rejectors and *A. clavatus*. An unexpected observation in this study was that carbaryl–bran bait applied with the standard 13.7-m swath width had no apparent effect on grasshopper populations. Control populations of individual species were generally too low for valid comparisons with treated populations. The results from the study may have been influenced by weather conditions. The Crighton blocks received heavy rains before and after treatments, and the ground remained wet for at least a week after treatments.

Wolf Coulee.—In the 13.7-m and 27.4-m swath-width blocks, the dominant species of grasshoppers were *M. sanguinipes*, *M. infantilis*, and *A. deorum* (table 58). These species together constituted 71.7 and 69.2 percent of grasshoppers at the 13.7-m and 27.4-m swath-width

blocks, respectively. At the control sites, *M. sanguinipes* and *M. infantilis* were also the two dominant species. On the pretreatment date, July 17, 1993, 80.4 percent of grasshoppers were second through fourth instars (table 54); adults constituted only 2.0 percent of grasshoppers. Pretreatment densities of total grasshoppers at the 13.7-m swath-width block, 27.4-m swath-width block, and at the control sites were 9.4 ± 2.0, 9.2 ± 0.9, and 8.0 ± 1.4 per m^2, respectively (table 59). Most of the grasshoppers at these sites were bran-accepting species. Mean densities of bran rejectors and bran-vulnerable species were below 1 per m^2. *M. sanguinipes* was the only species with a density exceeding 2 per m^2 at the three sets of evaluation sites. There were no significant differences between pretreatment densities in the treated blocks and control sites for total grasshoppers, bran acceptors, bran rejectors, bran-vulnerable species, *M. sanguinipes*, or *M. infantilis* ($P > 0.05$).

Two days after treatment with carbaryl–bran bait, the density of all grasshoppers combined declined by 78.2 ± 5.5 and 71.0 ± 7.8 percent in the 13.7-m and 27.4-m swath-width blocks, respectively (table 59, fig. 33a). Densities at the treated sites remained relatively low throughout July. At the control sites, mean density also declined initially by 45.7 ± 6.8 percent, but control populations eventually increased.

Populations of all bran acceptors combined and *M. sanguinipes* followed patterns similar to those for all grasshoppers combined (table 59, fig. 33b,c). Although their pretreatment densities were rather low, *M. infantilis* (fig. 33d) and *A. deorum* (fig. 33e) populations followed trends similar to those for all grasshoppers combined.

Results from the Wolf Coulee study suggest that both the standard and extended swath-width application of carbaryl–bran bait were effective in reducing grasshopper populations. The mean density of grasshoppers at the control sites declined immediately after the treatment date, but it soon increased to near the pretreatment level. The high proportion of bran-accepting species at the treatment blocks probably accounts for the overall high degree of efficacy of the carbaryl–bran bait.

Corral Creek.—In the 13.7-m swath-width block, the 27.4-m swath-width block, and at the and control sites, *M. sanguinipes* and *M. infantilis* were the dominant species, constituting 72.6, 77.2, and 79.3 percent of grasshoppers, respectively (table 60). At the time of treatment, 61.4 percent of grasshoppers were third and fourth instars; only 2.8 percent were adults (table 54).

Pretreatment densities of total grasshoppers at the 13.7-m swath-width block, the 27.4-m swath-width block, and the control sites were 10.1 ± 2.0, 11.9 ± 1.9, and 7.1 ± 1.1 per m^2, respectively (table 61). Most grasshoppers were bran-accepting species. Densities of bran rejectors and bran-vulnerable species were under 1 per m^2. Only densities of *M. sanguinipes* exceeded 2 per m^2 at the 13.7-m swath-width block and control sites. Densities of *M. sanguinipes* and *M. infantilis* exceeded 2 per m^2 at the 27.4-m swath-width sites. There was no significant difference in pretreatment densities at the treated and control sites for any grasshopper group ($P > 0.05$).

Density of total grasshoppers in the 27.4-m swath-width block declined by 40.1 ± 8.5 percent within 2 days of treatment (table 61, fig. 34a). Densities did not change appreciably at the 13.7-m swath-width or control sites. Average July 1992 densities were reduced by 41.7 ± 9.2 and 48.2 ± 6.8 percent in the 13.7-m and 27.4-m swath-width blocks, respectively. However, densities also declined by 36.9 ± 5.2 percent at the control sites.

Populations of total bran acceptors, *M. sanguinipes*, and *M. infantilis* followed trends similar to those for all grasshoppers combined (table 61, fig. 34b,c,d).

The results from the Corral Creek study suggest that the standard and extended swath-width applications of carbaryl–bran bait were moderately effective in reducing densities of grasshoppers. Because of the decline in densities at the control sites, however, it is difficult to determine the actual level of efficacy of the two treatments. The results from the Corral Creek study must also be viewed with caution because the area received considerable rainfall on the treatment date and on the posttreatment sampling dates.

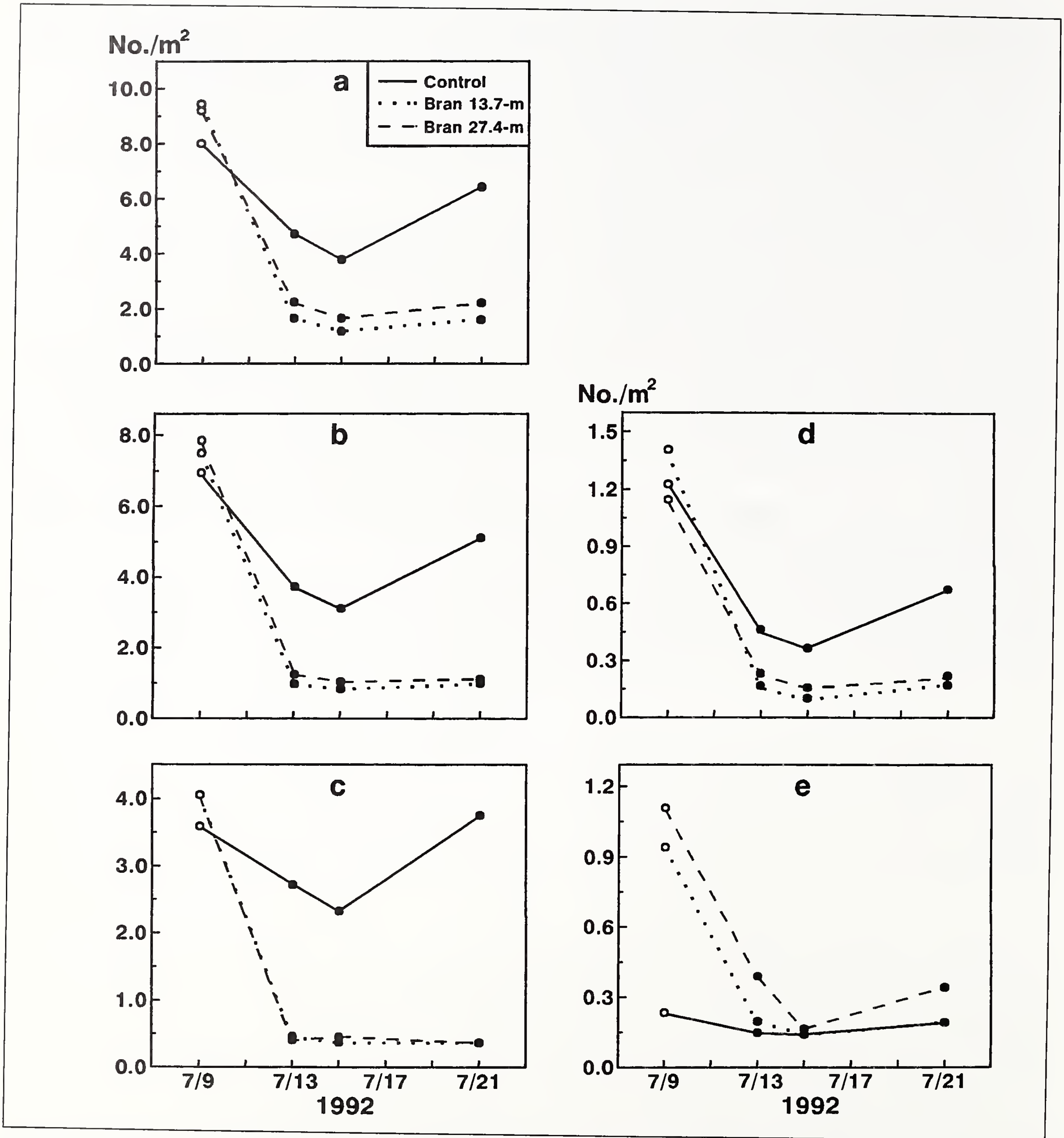

Figure 33—Population dynamics of total grasshoppers (a), bran acceptors (b), *M. sanguinipes* (c), *M. infantilis* (d), and *A. deorum* (e) at the Wolf Coulee block treated with aerial applications of carbaryl–bran bait using a standard and extended swath width and control sites. The open circles represent pretreatment densities. Values indicate means. Standard errors omitted for clarity (but see table 59).

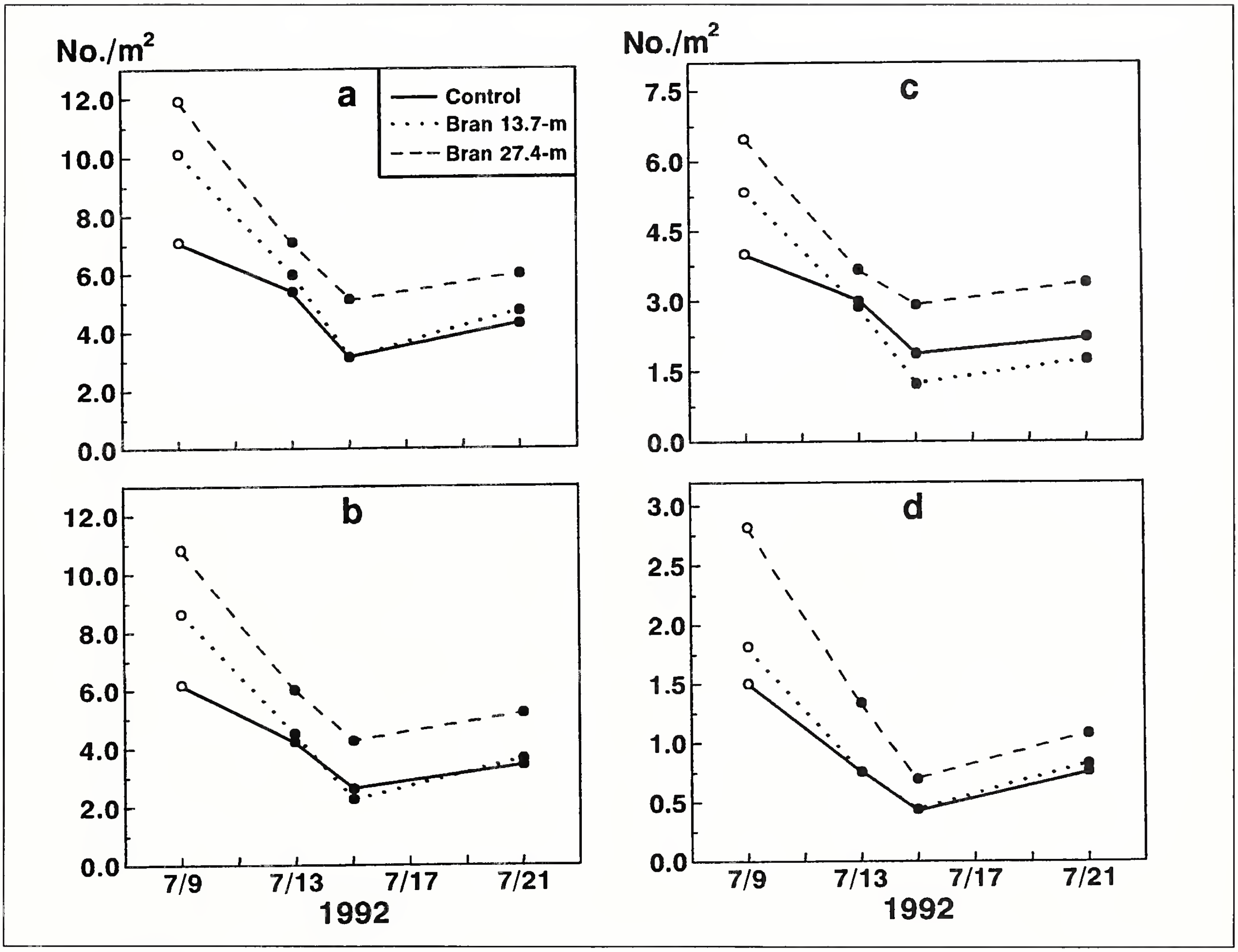

Figure 34—Population dynamics of total grasshoppers (a), bran acceptors (b), *M. sanguinipes* (c), and *M. infantilis* (d) at the Corral Creek block treated with aerial applications of carbaryl–bran bait using a standard and extended swath width and control sites. The open circles represent pretreatment densities. Values indicate means. Standard errors omitted for clarity (but see table 61).

Discussion

Evaluations of large-scale grasshopper control programs are usually limited to highly subjective and qualitative visual estimates of grasshopper populations. Such evaluations do not yield unbiased and precise estimates of large-scale program efficacy. Some estimates of grasshopper treatment effects used in economic models are based on data from small research plots. Data from small plots do not reflect the spatial and temporal dynamics of grasshopper populations and do not necessarily provide a realistic assessment of mortality achieved in large-scale programs. Small-plot studies may be useful for evaluating the immediate impact of a treatment, but because they cannot take grasshopper movement into consideration, they are far less useful for evaluating long-term effects.

The North Dakota GHIPM Demonstration Project was designed to evaluate the effectiveness of a large-scale IPM program for rangeland grasshoppers. Results from the 7-year study indicated that the IPM program was effective in controlling grasshopper infestations on a regional scale. Overall, grasshopper densities in the demonstration block were lower than or similar to densities in the standard block, where conventional chemical control treatment methods were used. In 5 of 7 years of the study, mean densities of grasshoppers at the untreated control sites in eastern Montana exceeded mean densities at the North Dakota treatment blocks. The frequency distributions of grasshopper densities at the sampling sites suggest that grasshopper infestations were generally larger at the control sites than in the demonstration or standard blocks.

Results from the study showed definite benefits from increasing the sampling intensity so that small areas of infestation could be identified and treated. Nearly twice as many hectares were treated in the standard block as in the IPM demonstration block, causing 2.5 times more insecticide active ingredient to be applied to rangeland in the standard block as to rangeland in the demonstration block. Use of the IPM program reduced total costs by 39 percent. This savings estimate includes the expense of applying *Nosema*–bran bait, which accounted for 45 percent of the total cost of all treatment in the demonstration block. Had carbaryl–bran bait been used to treat the 10,724-ha (26,499-acre) Tobacco Garden block instead of the more costly and less effective *Nosema* bait, the IPM program would have cost 56 percent less than the standard treatment program. Note that these cost savings from implementing an IPM program for grasshoppers do not include any environmental benefits associated with a reduction in insecticides; neither do they include the cost of increasing survey time.

Both immediate and second-year effects of treatments were evaluated in the GHIPM Demonstration Project. As expected, the most efficacious treatments in the demonstration block were the aerial applications of malathion and carbaryl sprays. The immediate reduction in total grasshopper populations in the nine blocks treated with these insecticides ranged from 84 to 99 percent. Other studies have shown similar reductions after treatment with nonselective insecticidal sprays (e.g., Onsager 1978, Foster et al. 1983, Mukerji and Ewen 1984, Quinn et al. 1989, Reuter et al. 1993, Bouaichi et al. 1994). Because carbaryl sprays consistently cause large reductions in grasshoppers, they probably also caused substantial reductions when used in the standard block.

The carbaryl–bran bait treatments were less efficacious than the insecticidal sprays. Immediate reductions in grasshoppers in the 22 treated populations averaged 44.5 percent (ranging from a mean 78.2-percent reduction to a mean 10.5-percent increase). In contrast, there was a mean 3.3-percent decrease in grasshopper populations in the 18 sets of controls associated with the bait treatment blocks. No single method of applying insecticidal bait was most effective in causing immediate reductions in grasshoppers. Population reductions in the three large blocks treated with the standard aerial application of carbaryl–bran bait ranged from only 17.4 percent to 54.6 percent. Mean population reductions in blocks receiving ground applications of insecticidal bait ranged from 21.4 to 69.0 percent.

The moderate levels of control from the insecticidal baits were similar to mortalities reported in other studies with carbaryl–bran baits. For example, researchers have reported 36 percent mortality (Jech et al. 1993) and 47 percent mortality (Quinn et al. 1989) after treatment with 2–5 percent (AI) carbaryl–bran bait at 1.1–1.5 kg/ha (1.0–1.3 lb/acre), 47 percent mortality after treatment with 6.7-percent (AI) carbaryl–bran bait at 3 kg/ha (2.7 lb/acre) (Mukerji and Ewen 1984), and 65–67 per-

cent mortality after treatment with 2-percent (AI) carbaryl–bran bait at 1.68–2 kg/ha (1.5–1.8 lb/acre) (Onsager et al. 1980a,b; Johnson and Henry 1987). In a review of the efficacy of insecticidal baits, Ewen (1990) reported that several insecticides formulated as baits (i.e., dimethoate, fenitrothion, carbofuran, cloethocarb, and possibly carbaryl and malathion) were as effective as sprays in reducing grasshopper populations below economic injury levels.

The efficacy of insecticidal baits is influenced by the species composition of grasshoppers in the treated area. If bait-rejecting species make up a relatively large percentage of grasshoppers in the treated area, the overall efficacy is likely to be lower. The relatively low grasshopper mortality rates caused by insecticidal baits reported by Quinn et al. (1989), Jech et al. (personal communication), and Jech et al. (1993) may have reflected the relatively low proportion of bran-accepting grasshopper species in the treated areas (43–57 percent in the studies cited). The relatively high mortality rates caused by insecticidal baits reported by Onsager (1980a,b), Johnson and Henry (1987) and Ewen (1990) were in plots with a high proportion of bran-accepting species (probably more than 85 percent in their studies). Onsager (1978) estimated that, on average, because of feeding preferences, molting, and chance events, only 75 percent of grasshoppers in an area are susceptible to insecticidal baits. In the North Dakota GHIPM Demonstration Project, there was a weak negative relationship between the percentage of bran-rejecting grasshopper species in a treated area and the percentage reduction of grasshoppers immediately after treatment ($r = -0.41$, $P < 0.06$, $n = 22$).

The overall success of insecticidal bait as a control method also depends on grasshopper density. Because insecticidal baits are generally less efficacious than sprays, single treatments at the standard rate may not produce satisfactory results if initial grasshopper populations are too high. In five of the six blocks treated with ground applications of carbaryl–bran bait, initial grasshopper densities ranged from 23.9 to 51.3 per m^2. Four of these blocks needed to be treated a second time to reduce grasshopper populations to a more acceptable level. In these studies, additional applications of insecticidal bait were economically feasible because only small areas were treated with ground equipment. When large infestations occur, treatment with multiple aerial applications of carbaryl–bran bait may not be cost effective. Foster et al. (1999) found, for example, that double and triple aerial applications of carbaryl–bran bait were only slightly better than a single application and that any increase in grasshopper mortality associated with multiple aerial applications was unlikely to be cost effective because of the expense of such applications. Applying additional bait in a single application is more cost effective than resorting to multiple applications.

An additional aspect of treatment efficacy is its duration. Most grasshopper treatment programs provide excellent control of grasshopper populations throughout the year of treatment. Excellent control in the year of treatment was found in most of the blocks treated in the North Dakota GHIPM Demonstration Project. The only exception was in the Redwing block treated with malathion spray, where populations of total grasshoppers rebounded slightly over a month after treatment because of the prevalence of late-hatching species. The size of the treated block had no apparent effect on grasshopper densities during the summer after initial treatment. For example, in the six small blocks treated with ground applications of carbaryl–bran bait, total grasshopper densities remained fairly constant after treatment. Thus, obvious reinvasion of these small blocks did not occur.

Ideally, treatments should suppress grasshopper populations for more than a year. In a review of several long-term grasshopper control programs, Blickenstaff et al. (1974) reported that only two of nine control programs resulted in protection after the first year. Blickenstaff et al. (1974) also reviewed the incidence of retreatments in grasshopper control programs in Wyoming from 1952 to 1958. They found that only 4.7 percent of treated acreage was retreated the following year. Jech et al. (1993) studied the second-year effects of diflubenzuron– and carbaryl–bran baits on grasshoppers in South Dakota. They found that treatments did not have a significant effect on total populations of grasshoppers but did suppress populations of *A. deorum* and *P. quadrimaculatum* during the year after treatment. In another study of the effects of carbaryl-bran bait and malathion spray on grasshoppers in South Dakota, Quinn et al. (1989) reported that treatments had no apparent effect on

second-year populations of all grasshoppers combined but that densities of *A. deorum* were suppressed during the year after treatment.

In contrast, Swain (1986) found that total grasshopper populations in a New Mexico study area remained suppressed a year after treatment in plots treated with carbaryl–bran bait, carbaryl sprays, and malathion sprays, while populations in control plots did not change. Swain's study was one of the few to include replicated plots. Pfadt et al. (1985) similarly reported that aerial application of malathion spray applied to rangeland in Wyoming reduced second-year densities of grasshoppers in treated plots, while populations remained high in a control plot. Unfortunately, control plots were not replicated in Pfadt's study. Pfadt and Hardy (1987) reviewed results from a grasshopper control study conducted in Wyoming beginning in 1973. They found that second-year densities of all grasshoppers combined declined by 58 to 98 percent at seven sites treated with malathion spray. Second-year densities at two untreated sites declined by 24 and 53 percent, respectively. Nevertheless, the investigators concluded that control of rangeland grasshoppers lasted an average of 5 years.

Long-term suppression of grasshoppers may not occur or be detected for several reasons (Blickenstaff et al. 1974). A primary reason is that grasshopper populations often decline naturally after the year of treatment, thus obscuring or negating any long-term treatment effects. Using a two-state Markov chain model to estimate the likelihood of change among grasshopper populations in Montana, Kemp (1987) found that the probability of a high grasshopper population declining to low levels ranged from 0.18 to 0.31 in three Montana counties. Using the same method, Lockwood et al. (1988) reported that the probability of an infested county in Montana (more than 9.6 grasshoppers per m^2) changing to an uninfested condition (fewer than 9.6 per m^2) ranged from 0.09 to 0.43, depending on the county. In the North Dakota GHIPM Demonstration Project, grasshopper populations declined naturally after 1987 (fig. 9), as indicated by a reduction in the control population, perhaps because of severe drought in the area (Kemp and Cigliano 1994). Thus, second-year treatment effects could not be detected easily in studies initiated in 1987 within the demonstration block.

Other reasons for the lack of long-term control as reported in some studies include (1) reinvasion of the treated area by grasshoppers outside of the treated area, (2) high fecundity and survival of some grasshopper species caused by favorable weather conditions, (3) the occurrence of 2-year life cycles in species occurring at high altitudes, (4) extended hatching periods beyond the control date, (5) the presence of late-hatching species, (6) the failure to treat the entire area of infestation, and (7) the use of insecticidal baits or other methods that do not produce high levels of mortality. The final reason just cited may explain why Jech et al. (1993) and Quinn et al. (1989) did not find second-year suppression of grasshoppers in areas treated with insecticidal baits.

Nineteen field experiments in the North Dakota GHIPM Demonstration Project examined changes in grasshopper populations a year after treatment. The single study of *Nosema*–bran bait showed no apparent immediate or subsequent population changes after the application. Overall, at the 18 other study sites, grasshopper populations declined by an average of 53.2 percent 1 year after treatment (i.e., a comparison of pretreatment densities with average densities during July of the following year). In contrast, densities at the control sites increased by an average of 33.6 percent. Figure 35 summarizes population changes at the treatment and control sites in the various studies. The solid, equal compensation line shows where second-year densities were equal to pretreatment densities. Populations close to this line rebounded to near pretreatment levels a year after treatment. The dotted line indicates a 25- percent reduction from equal compensation. A year after treatment, nine of the control populations were near or above this equal compensation line, while six were below 25 percent of the pretreatment population. In contrast, only 4 of 18 treated populations were within 25 percent of the equal compensation line (i.e., above the dotted line). Of the four grasshopper populations that rebounded to near pretreatment levels, three had received hot-spot treatments with carbaryl–bran bait and had had relatively high initial densities; one had been treated with aerial applications of carbaryl–bran bait but had had low initial densities.

The data in figure 35 suggest that treatments were, in general, effective in suppressing grasshopper populations

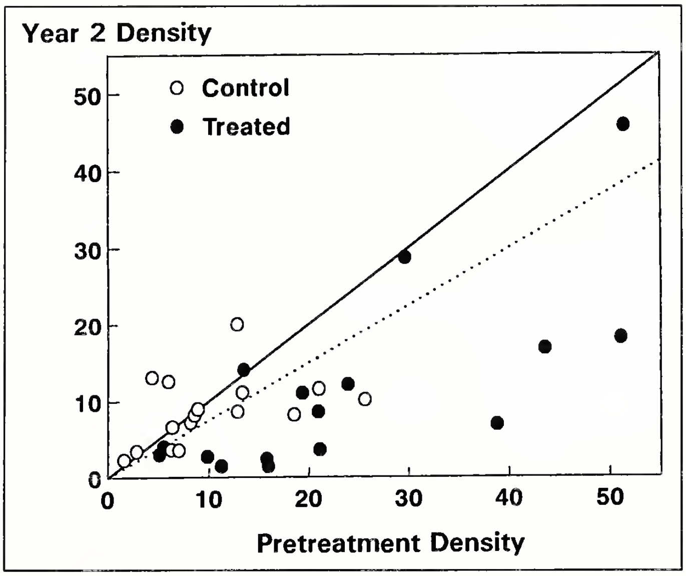

Figure 35—Relationship between second-year and pretreatment densities of total grasshoppers at the 17 treated sites where 2 years of data were available, and their corresponding control sites. The solid line indicates where second-year densities were equal to pretreatment densities. The dotted line indicates a 25-percent reduction from equal compensation.

a year after treatment. This conclusion is also supported by data on the incidence of retreatments within the standard block. From 1985 to 1993, only 0.1 percent of the treated sections of rangeland needed to be treated the following year. As discussed above, other studies have come to similar conclusions based on changes in grasshopper populations in treatment and control blocks or on the incidence of retreatment. These results should be interpreted with caution because in some cases the untreated control populations and communities of grasshoppers were different from the treated populations. Differences in species composition between treatment and control populations can occur when an entire area of infestation is included in a treatment block. It is sometimes difficult to find matching control populations because if their densities are similar to densities of treated populations, they should be included in the treatment program so they are not able to reinfest the treated area.

Of the 18 treated populations of grasshoppers studied, 8 had corresponding control populations that were similar in species composition and density. Four of such treated populations (i.e., Cherry Creek, Charlie Creek, Antelope–Sevin Spray, Antelope–Bran) remained at low levels a year after treatments, while their corresponding control populations did not change. One such treated population, Redwing Creek, was reduced a year after treatment, but so was the corresponding control population. Of the eight treated populations with good matching controls, three rebounded to or near pretreatment levels a year after treatment (i.e., North River, Elkhorn, Cottonwood Creek II). Of these, second-year populations at North River and Elkhorn increased because of an increase in the bran-rejecting species *A. clavatus*. The increase at Cottonwood Creek II may have been related to the small size of the treated area (i.e., 41 ha or 101 acres).

Eight of the 10 other treated grasshopper populations had corresponding controls with very different species compositions and pretreatment densities. Five such treated populations showed reductions a year after treatment, and three rebounded to pretreatment levels. When treated and control communities are different, it is generally assumed that population trends around the time of treatments are the same for grasshopper populations in the treated and control areas. Second-year populations in the other two treatment blocks (i.e., Sather Lake and Southwest) were also reduced, but control populations were not available for comparisons.

IPM programs have been particularly effective in managing insect pests in agricultural systems (Horn 1988), but many of the IPM tactics used against agricultural pests are not yet applicable to rangeland systems. Table 62 compares agricultural and rangeland systems and the IPM tactics that are available for managing their insect pest problems. IPM of grasshoppers on rangeland is much more complicated than IPM of agricultural pests because of the complexity of the rangeland system. The most notable difference is that rangeland harbors numerous species of native grasshoppers that feed on numerous plant species. For example, Quinn et al. (1991a) identified 40 species of grasshoppers, 14 grass species, and 45 species of forbs at 30 0.75-ha research sites within a 100-km^2 area in northwestern South Dakota in a single month. Pest and plant diversity in agroecosystems is generally low, with only a few species of insects feeding on monocultures of plants. The great diversity of plants and pests found on rangeland results in a great diversity

of other arthropods and vertebrates on rangeland (Quinn et al. 1990, 1991b, 1993, 1995; Walter 1987).

Comparatively few management tactics are available for grasshoppers on rangeland. Whereas agricultural systems often utilize host–plant resistance and cultural controls to manage insect pests, such methods are generally not used in rangeland systems. The use of resistant plants is not feasible in most rangeland situations for two reasons: (1) grasshoppers, as a group, have a very wide diet breadth (Mulkern et al. 1964) and (2) rangeland plant communities are heterogeneous. Cultural controls, which include crop rotation, trap cropping, and management of soil fertility, are often important pest-management options in agricultural systems. Although it may not be feasible to use many cultural control methods on rangeland on a large scale, it may be possible to manage some grasshopper populations through better management of livestock grazing. There has been considerable concern that overgrazing of rangeland contributes to grasshopper infestations (Nerney 1958, Holmes et al. 1979, Fleischner 1994), although studies suggest that grazing may affect grasshopper community composition but not necessarily densities (Capinera and Sechrist 1982, Quinn and Walgenbach 1990, Fielding and Brusven 1993). Optimal timing of grazing may increase plant biomass and nutrient content (Manske 1995) and alter soil characteristics that affect grasshopper egg development, production, and survival (Onsager 1995).

Classical biological control with introduced parasites or predators is an essential aspect of many IPM programs in agricultural systems (DeBach and Rosen 1991). In contrast, biological control of grasshoppers with exotic species has rarely been attempted (Prior and Greathead 1989, Greathead 1992). USDA has considered the release of the grasshopper egg parasite *Scelio parvicornis* Dodd, collected from Australia (Dysart 1991). However, this proposal has generated considerable controversy (Lockwood 1993, Carruthers and Onsager 1993), and parasite introductions have not occurred. Native natural enemies may cause significant mortality among grasshoppers (Parker and Wakeland 1957, Joern 1986, Capinera 1987) and some have suggested that grasshopper population can be regulated by natural enemies under certain conditions (Belovsky and Slade 1993). Preservation of natural enemies, along with other nontarget species, has been an emphasis in the development and use of insecticidal baits and microbial control agents (USDA 1987).

Microbial control agents are important aspects of IPM programs for many agricultural pests. In particular, the bacterium *Bacillus thuringiensis* has been adopted as an essential microbial insecticide for numerous lepidopteran and coleopteran pests. Considerable research has been conducted on microbial control agents for grasshoppers (Mason and Erlandson 1994, Dysart and Hostetter 1995). The protozoan parasite *N. locustae* Canning, has been registered in the United States as a biological control agent for grasshoppers. It is formulated by applying spores of the protozoan to wheat bran. Mortality of field populations of grasshoppers after application of *Nosema*–treated bait has ranged from 30 to 60 percent (Henry 1972; Henry et al. 1973, 1978; Ewen and Mukerji 1980; Johnson 1989). An advantage of *Nosema*–bran bait as a control measure is that this bait may, potentially, suppress grasshopper populations over a long period of time. Theoretically, high rates of infection with *N. locustae* may produce high rates of transmission to subsequent generations of grasshoppers (Henry and Oma 1981). An additional advantage is that *N. locustae* has little effect on beneficial and other nontarget organisms. Thus, *Nosema*–bran bait may be particularly useful in environmentally sensitive areas were conventional insecticides cannot be used.

Unfortunately, *Nosema*–bran bait is frequently not a viable option for controlling grasshoppers because of its cost and low efficacy (Mason and Erlandson 1994). An independent review team—established by the USDA–APHIS sponsored Cooperative GHIPM Project to assess the utility of *N. locustae* for controlling grasshoppers—came to the following conclusions (Vaughn et al. 1995): (1) *N. locustae* should be used for grasshopper control in environmentally sensitive areas where cost and acute insecticide control are not primary concerns; (2) higher application rates and multiple applications of *N. locustae* should be used where environmental sensitivities outweigh the higher costs involved; and (3) the use of *N. locustae* at currently recommended dosages does not reliably provide an adequate level of suppression.

Other microbial control agents that are being examined for future use in grasshopper control programs include the fungi *Beauveria bassiana*, *Metarhizium* spp., and *Entomophaga* spp. (Foster et al. 1991, Foster 1993, Mason and Erlandson 1994, Foster and Britton 1995, Dysart and Hostetter 1995).

In rangeland systems as in agricultural systems, considerable progress has been made in monitoring and forecasting insect infestations and in developing decision-support software. Several models have been developed for predicting grasshopper population dynamics (Gage et al. 1976, Hardman and Mukerji 1982, Kemp and Onsager 1986, Mann et al. 1986) and the impact of grasshoppers on rangeland (Torell and Huddleston 1987, Torell et al. 1989, Davis et al. 1992). Models of forage growth and grasshopper population dynamics have been incorporated into the HOPPER expert systems for managing grasshoppers (Berry et al. 1991, 1992; Larsen and Foster 1995). HOPPER can be used to choose the most economically and environmentally sound treatment method from a variety of options.

The use of insect-resistant plants, cultural and biological controls, and microbial insecticides has greatly decreased the use of chemical insecticides in most agricultural systems. Because few such alternatives are available for grasshopper control programs, such programs continue to rely heavily on chemical insecticides. However, considerable progress has been made in developing and applying methods that reduce the amount of insecticide applied to rangeland. These methods include using insecticidal baits (Ewen 1990), modifying equipment to consistently apply bait uniformly by air (Foster and Roland 1995), reducing spray rates (Foster et al. 1979, Reuter et al. 1993), reducing spray rates in combination with increasing swath spacing (Larsen and Foster 1995), and treating small areas of grasshopper infestation to prevent larger outbreaks. Historically, the goal of grasshopper management programs has been to achieve maximum control. Today, with HOPPER, our goals also emphasize the most economically justified treatment action.

Two main advantages of insecticidal baits over insecticidal sprays are that bait applications use much less toxicant and preserve communities of natural enemies. Carbaryl used as an aerial spray, for example, is typically applied at 0.42–0.56 kg AI per hectare (0.37–0.50 lb AI per acre) (Foster and Onsager 1995a). In comparison, only 0.03 kg AI per hectare (0.03 lb AI per acre) is used when carbaryl is applied as a bait, a greater than 92 percent difference. Insecticidal baits have less impact on populations of nontarget species than insecticidal sprays do because baits affect only species that consume treated bait or those that have fed on it (Quinn et al., 1990, 1991b, 1993; Gregory et al. 1992; Peach et al. 1994). A significant disadvantage of insecticidal baits is that some grasshopper species will not consume baits. Thus, the overall efficacy of insecticidal baits depends on the species composition of grasshoppers, which, in turn, depends on the plant community and soil characteristics of the habitat (Kemp et al. 1990, Quinn et al. 1991a, Fielding and Brusven 1993).

Grasshopper control programs today typically involve the treatment of large areas (i.e., exceeding 4,047 ha or 10,000 acres of rangeland) after infestations occur. In some cases, however, it might be possible to treat small areas of infestation, or hot spots, to prevent future buildups of grasshopper populations. This approach should be particularly effective if grasshoppers have eruptive outbreaks that expand from focal points (Berryman 1987, Lockwood and Brewer 1993 unpubl., Lockwood et al. 1995). Hot-spot treatments were one of the experimental treatments used in the demonstration block. Grasshopper populations in the three small blocks treated with ground applications of malathion sprays were reduced substantially immediately after treatment; however, there was no evidence that second-year populations were reduced. Hot-spot ground applications of carbaryl–bran bait similarly caused immediate reductions in grasshopper populations. Second-year populations were also reduced in two of the six field studies. However, because control populations were different from populations in the treated areas, it cannot be concluded that the insecticidal baits caused the lower densities a year after treatment.

The other experimental treatment was the application of carbaryl–bran bait to four blocks using an extended swath width. This approach was used to determine whether the extended swath width could be used to reduce the application costs of insecticidal baits and still maintain adequate reductions in grasshopper populations. Results from these studies were inconclusive. One study showed that the standard swath width was most effective in reducing grasshopper populations, while another study showed that the extended swath width was most effective. Results from the other two studies indicated that the standard and extended swath width were equally effective.

The North Dakota GHIPM Demonstration Project relied heavily on increased sampling, better delineation of grasshopper infestations, and the use of methods to reduce the amount of insecticide and application costs. These methods included using insecticide baits, ground treatment of localized grasshopper infestations, and extended swath widths for aerial applications. However, if future grasshopper infestations are to be controlled in a truly integrated manner, then it is clear that new preventive tools and tactics, as well as nonchemical insecticides, need to be developed and incorporated into grasshopper control programs.

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Table 1—Total area treated on Federal, State, and private land in the Western United States for grasshopper and Mormon crickets[a]

Year	Total area treated (ha)
1972	890,311
1973	1,052,186
1974	330,629
1975	263,047
1976	345,198
1977	563,324
1978	330,225
1979	2,913,746
1980	2,144,841
1981	515,167
1982	234,718
1983	0
1984	87,817
1985	5,299,781
1986	2,776,901
1987	549,264
1988	207,916
1989	43,314
1990	103,512
1991	80,582
1992	95,208
1993	34,470
1994	33,986
1995	1,199

[a]From APHIS administrative data.

Table 2—Description of the North Dakota Grasshopper Integrated Pest Management Project

Block	Area (km^2)	Counties, State	Grasshopper surveys	Insecticide treatments	Size of areas treated (ha)
Demonstration	3,431	McKenzie, North Dakota	Nymph Delineating Pre- and post-treatment adult Final adult	Malathion spray Carbaryl spray Carbaryl bait *Nosema*	10 to 15,022
Standard	5,294	Golden Valley, Slope, and Billings, North Dakota	Nymph Delineating Final adult	Carbaryl spray Carbaryl bait	> 4,047
Control	4,373	Wibaux, Dawson, and Richland, Montana	Nymph Final adult	None	None

Table 3—Grasshopper control treatments used in the demonstration and standard blocks

Insecticide	Formulation[a]	Application method	kg AI/ha
Carbaryl spray	Sevin 4-oil	Aerial application; ultralow-volume spray	0.56
Carbaryl bait	2% Sevin 4-oil on wheat bran	Aerial application of 1.68 kg bait/ha; standard and extended swath width	0.03
Carbaryl bait	2% Sevin 4-oil on wheat bran	Ground application of 2.24 kg bait/ha	0.06
Malathion spray	Malathion-ULV concentrate	Aerial application; ultralow-volume spray	0.65
Nosema bait	*Nosema locustae* on wheat bran	Aerial application of 1.12 kg bait/ha	2.5×10^9 spores/kg bait

[a] Active ingredients in Sevin-4-oil and Malation ULV are 1-naphthyl N-methylcarbamate and O,O-dimethyl phosphorodithioate of diethyl mercaptosuccinate, respectively.

Table 4—Number of sites and sections (259-ha blocks) sampled during the adult survey in the demonstration and standard blocks from 1987 to 1993

Year	Block	No. of sections sampled	Proportion of[a] all sections sampled	No. of sites sampled
1987	Demonstration	439	0.33	460
	Standard	191	0.16	193
1988	Demonstration	483	0.36	513
	Standard	218	0.19	231
1989	Demonstration	635	0.48	723
	Standard	215	0.18	217
1990	Demonstration	667	0.50	797
	Standard	230	0.20	235
1991	Demonstration	705	0.53	869
	Standard	194	0.17	201
1992	Demonstration	565	0.43	712
	Standard	502	0.43	529
1993	Demonstration	498	0.38	521
	Standard	397	0.34	400
Avg.	Demonstration	570	0.43	656
	Standard	278	0.24	287

[a] Based on a total of 1,167 and 1,325 sections for the standard and demonstration blocks, respectively.

Table 5—Areas treated for grasshoppers in the North Dakota Grasshopper Integrated Pest Management Program

Year	Location	Treatment	Hectares treated	Dates treated
Demonstration Block				
1987	Tobacco Garden	*Nosema*–bran bait[b]	10,724	22–26 June
	Southwest	Standard malathion spray[c]	8,935	5 Aug
	Sather Lake	Standard malathion spray[c]	15,022	7–8 July
	Squaw Gap[a]	Standard malathion spray[c]	110	unknown
	1987 TOTAL		34,791	
1988	North River	Standard carbaryl–bran bait[d]	2,064	17–20 June
	Elkhorn	Standard carbaryl–bran bait[d]	731	21 June
	McNany	Hot-spot treatment: malathion spray[c]	259	2 July
	Mormon Butte[a]	Standard malathion spray[c]	259	unknown
	Tarnavsky[a]	Standard malathion spray[c]	259	unknown
	1988 TOTAL		3,572	
1989	Blue Butte	Hot-spot treatment: malathion spray[c]	129	19 July
	1989 TOTAL		129	
1990	Tobacco Garden–Bait	Hot-spot treatment: carbaryl–bran bait[e]	60	10 July
	Tobacco Garden–Bait	Hot-spot treatment: carbaryl–bran bait[e]	43	18 July
	Hay Draw	Hot-spot treatment: carbaryl–bran bait[e]	10	16 June
	Hay Draw	Hot-spot treatment: carbaryl–bran bait[e]	10	22 June
	Cottonwood Creek	Hot-spot treatment: carbaryl–bran bait[e]	85	18–25 June
	Cottonwood Creek	Hot-spot treatment: carbaryl–bran bait[e]	85	28 June
	Antelope Creek	Hot-spot treatment: carbaryl–bran bait[e]	38	22 June
	Antelope Creek	Hot-spot treatment: carbaryl–bran bait[e]	38	16 July
	Cherry Creek	Standard malathion spray[c]	3,704	8 July
	Redwing Creek	Standard malathion spray[c]	1,522	4–5 July
	1990 TOTAL		5,595	
1991	Hay Draw	Hot-spot treatment: carbaryl–bran bait[e]	10	11 June
	Cottonwood II	Hot-spot treatment: carbaryl–bran bait[e]	41	18 June
	Schapers	Hot-spot treatment: carbaryl–bran bait[e]	46	27 June
	Hovet	Hot-spot treatment: malathion spray[c]	366	27 June
	Antelope–Bran	Standard carbaryl–bran bait[d]	2,550	8–10 July
	Antelope–74	Standard carbaryl spray[f]	7,798	13–15 July
	1991 TOTAL		10,811	

Table 5—Areas treated for grasshoppers in the North Dakota Grasshopper Integrated Pest Management Program *(continued)*

Year	Location	Treatment	Hectares treated	Dates treated
Demonstration Block *(continued)*				
1992	Mead	Extended swath width: carbaryl–bran bait[g]	438	11 July
	Mead	Extended swath width: carbaryl–bran bait[g]	607	10 July
	Creighton	Extended swath width: carbaryl–bran bait[g]	705	8 July
	Creighton	Extended swath width: carbaryl–bran bait[g]	709	9 July
	Charlie Creek	Standard malathion spray[c]	1,347	21 July
	1992 TOTAL		3,806	
1993	Wolf Creek	Extended swath width: carbaryl–bran bait[g]	172	19 July
	Wolf Creek	Extended swath width: carbaryl–bran bait[g]	171	19 July
	Corral Creek	Extended swath width: carbaryl–bran bait[g]	162	20 July
	Corral Creek	Extended swath width: carbaryl–bran bait[g]	165	20 July
	Johnson Ranch	Standard carbaryl spray[f]	2,940	14–15 July
	1993 TOTAL		3,610	
All	GRAND TOTAL		62,314	
Standard Block				
1987	Golden Valley N.	Standard carbaryl spray[f]	13,976	
	Golden Valley S.	Standard carbaryl spray[f]	29,641	
	TOTAL 1987		43,617	
1991	Golden Valley S.	Standard carbaryl spray[f]	35,130	
	TOTAL 1991		35,130	
1992	South Medora	Standard carbaryl spray[f]	18,366	
	TOTAL 1992		18,366	
1993	Slope County	Standard carbaryl spray[f]	23,902	
	Amidon	Standard carbaryl–bran bait[d]	95	
	TOTAL 1993		23,997	
All	GRAND TOTAL		121,110	

[a] Treated for crop protection, not as part of the GHIPM Project.
[b] Aerial application of Nosema bait, 1.12 kg/ha (2.5×10^9 spores/ha).
[c] Aerial application of 0.58 L of Malathion-ULV Concentrate per hectare (0.65 kg AI/ha).
[d] Aerial application of 2% carbaryl–bran bait at 1.68 kg/ha (0.0336 kg AI/ha).
[e] Ground application of 2% carbaryl–bran bait at 2.24 kg/ha (0.0448 kg AI/ha).
[f] Aerial application of 1.46 L of Sevin-4-oil per hectare (0.56 kg AI/ha).
[g] Aerial applications of 2% carbaryl–bran bait at 1.68 kg/ha (0.0336 kg AI/ha), using 13.7- and 27.4-m swath widths.

Table 6—Total amount of active ingredient (kg) applied to rangeland in the demonstration and standard blocks from 1987 to 1993

		Insecticide treatment		
Block	Year	Malathion	Carbaryl spray	Carbaryl bait
Demonstration	1987	15,644	0	0
	1988	505	0	94
	1989	84	0	0
	1990	3,397	0	17
	1991	238	4,367	90
	1992	876	0	61
	1993	0	1,646	17
	Total	20,744	6,013	279
Standard	1987	0	24,426	0
	1988	0	0	0
	1989	0	0	0
	1990	0	0	0
	1991	0	19,673	0
	1992	0	10,285	0
	1993	0	13,385	3
	Total	0	67,764	3

Table 7—Treatment costs in the demonstration and standard blocks from 1987 to 1993

Treatment	Costs ($)[a] 1987	1988	1989	1990	1991	1992	1993	Total
Demonstration Block								
Carbaryl spray								
Toxicant:	0	0	0	0	42,694	0	16,097	58,791
Application:	0	0	0	0	12,555	0	4,733	17,288
Total:	0	0	0	0	55,249	0	20,830	76,079
Carbaryl–bait (aerial)								
Toxicant:	0	7,748	0	0	7,069	6,816	1,857	23,490
Application:	0	19,006	0	0	17,340	16,721	4,556	57,623
Total:	0	26,754	0	0	24,409	23,537	6,413	81,113
Carbaryl–bait (ground)								
Toxicant:	0	0	0	1,364	359	0	0	1,723
Application:	0	0	0	0	0	0	0	0
Total:	0	0	0	1,364	359	0	0	1,723
Malathion spray								
Toxicant:	57,929	1,870	311	12,579	881	3,242	0	76,812
Application:	38,748	1,251	208	8,414	589	2,169	0	51,379
Total:	96,677	3,121	519	20,993	1,470	5,411	0	128,191
Nosema–bait								
Toxicant:	91,403	0	0	0	0	0	0	91,403
Application:	142,807	0	0	0	0	0	0	142,807
Total:	234,210	0	0	0	0	0	0	234,210
GRAND TOTAL:	330,887	29,875	519	22,357	81,487	28,948	27,243	521,316
Standard Block								
Carbaryl spray								
Toxicant:	238,803	0	0	0	192,337	100,554	130,863	662,557
Application:	70,223	0	0	0	56,559	29,569	38,482	194,833
Total:	309,026	0	0	0	248,896	130,123	169,345	857,390
Carbaryl–bait (aerial)								
Toxicant:	0	0	0	0	0	0	263	263
Application:	0	0	0	0	0	0	646	646
Total:	0	0	0	0	0	0	909	909
GRAND TOTAL:	309,026	0	0	0	248,896	130,123	170,254	858,299

[a] Carbaryl spray: 1.46 l/ha, $3.75/l, $1.61/ha application costs.
Carbaryl–bait (aerial): 1.68 kg/ha, 2% AI, $1.65/kg, $6.80/ha application costs.
Carbaryl–bait (ground): 2.24 kg/ha, 2% AI, $1.65/kg, $0.00/ha application costs.
Malathion spray: 0.58 l/ha, $4.15/l, $1.61/ha application costs.
Nosema–bait: 1.12 kg/ha, $7.61/kg, $13.27/ha application costs.

Table 8—Relative abundance and distribution of species collected in the North Dakota GHIPM Demonstration Block from 1987 to 1993

Grasshopper variable	Frequency (% of total)	No. sites occupied
Melanoplus sanguinipes (Fabricius)	16.381	393
Melanoplus infantilis Scudder	15.422	390
Ageneotettix deorum (Scudder)	7.880	385
Camnula pellucida Scudder	7.243	301
Phlibostroma quadrimaculatum (Thomas)	6.650	299
Aeropedellus clavatus (Thomas)	6.541	357
Eritettix simplex (Scudder)	5.075	261
Psoloessa delicatula Scudder	3.899	238
Aulocara elliotti Thomas	3.709	311
Trachyrhachys kiowa Thomas	3.142	371
Melanoplus packardii Scudder	2.890	386
Phoetaliotes nebrascensis (Thomas)	2.804	262
Melanoplus femurrubrum (DeGeer)	2.624	263
Melanoplus confusus Scudder	2.437	343
Melanoplus gladstoni Scudder	1.779	294
Melanoplus bivittatus (Say)	1.711	272
Opeia obscura (Thomas)	1.608	252
Amphitornus coloradus (Thomas)	1.604	324
Melanoplus dawsonii (Scudder)	1.205	190
Arphia conspera Scudder	0.916	267
Xanthippus corallipes Haldeman	0.665	219
Encoptolophus costalis (Scudder)	0.653	158
Metator pardalinus (Saussure)	0.606	269
Hypochlora alba Dodge	0.420	199
Arphia pseudonietana (Thomas)	0.298	220
Boopedon nubilum (Say)	0.297	107
Melanoplus keeleri (Thomas)	0.287	170
Hesperotettix viridus (Scudder)	0.207	171
Mermiria bivittata (Serville)	0.160	135
Orphulella speciosa (Scudder)	0.140	106
Chortophaga viridifasciata (DeGeer)	0.114	101
Chorthippus curtipennis (Harris)	0.095	39
Spharagemon collare (Scudder)	0.053	70
Aulocara femoratum (Scudder)	0.050	56
Aeoloplides turnbulli (Caudell)	0.049	41
Melanoplus flavidus Scudder	0.045	19
Stenobothrus brunneus Thomas	0.042	26
Unknown *Melanoplus*	0.041	18
Dissosteira carolina (L.)	0.039	36
Unknown Oedipodinae	0.035	44
Melanoplus borealis (Fieber)	0.024	36

Table 8—Relative abundance and distribution of species collected in the North Dakota GHIPM Demonstration Block from 1987 to 1993 *(continued)*

Grasshopper variable	Frequency (% of total)	No. sites occupied
Hadrotettix trifasciatus (Say)	0.021	40
Spharagemon equale (Say)	0.020	46
Pardalophora haldemanii (Scudder)	0.019	48
Chloealtis conspersa (Harris)	0.018	29
Melanoplus foedus Scudder	0.018	17
Melanoplus angustipennis (Dodge)	0.013	13
Trachyrhachys aspera (Scudder)	0.008	8
Pseudopomala brachyptera (Scudder)	0.008	18
Acrolophitus hirtipes (Say)	0.008	18
Melanoplus occicdentalis (Thomas)	0.005	18
Derotmema haydeni (Thomas)	0.004	11
Dactylotum bicolor (Thomas)	0.003	10
Aeoloplides tenuipennis (Scudder)	0.002	2
Cordillacris occipitalis (Thomas)	0.002	6
Melanoplus tristis Bruner	0.002	2
Unknown grasshopper	0.002	3
Chloealtis abdominalis (Thomas)	0.001	2
Circotettix carlinianus (Thomas)	0.001	1
Cordillacris crenulata (Bruner)	0.001	2
Encoptolophus sordidus (Burmeister)	0.001	4
Melanoplus bowditchi Scudder	0.001	2
Trimerotropis pallidipennis (Burmeister)	0.001	3
Unknown Gomphocerinae	0.001	1
Circotettix rabula Rehn and Hebard	<0.001	1
Hippiscus ocelote (Saussure)	<0.001	1
Melanoplus lakinus (Scudder)	<0.001	1
Oedaleonotus enigma (Scudder)	<0.001	1
Orphulella pelidna (Burmeister)	<0.001	1
No. grasshoppers collected	394,599	
No. sites sampled		393

Table 9—Grasshopper species composition at the Tobacco Garden block and control sites on the pretreatment date, 21 June 1987

Species	% of total[a] *Nosema*–bait	% of total[a] Control
Melanoplus infantilis	25.70	33.26
Ageneotettix deorum	15.45	1.93
Melanoplus sanguinipes	11.36	14.16
Melanoplus dawsonii	8.57	25.32
Phlibostroma quadrimaculatum	5.98	0.21
Phoetaliotes nebrascensis	5.64	2.15
Opeia obscura	5.41	0.43
Trachyrhachys kiowa	3.13	2.36
Melanoplus sp.	2.79	0.00
Camnula pellucida	2.56	4.51
Aeropedellus clavatus	2.51	2.79
Unknown Oedipodinae	2.03	0.00
Orphulella speciosa	1.49	3.22
Stenobothrus brunneus	1.49	0.21
Amphitornus coloradus	1.04	0.00
Melanoplus keeleri	0.90	0.00
Melanoplus packardii	0.70	1.29
Melanoplus confusus	0.56	0.64
Boopedon nubilum	0.51	0.00
Melanoplus bivittatus	0.48	4.94
Hesperotettix viridus	0.34	0.21
Arphia pseudonietana	0.31	0.43
Aulocara elliotti	0.28	0.00
Metator pardalinus	0.17	0.21
Melanoplus femurrubrum	0.11	0.00
Eritettix simplex	0.08	0.21
Hypochlora alba	0.08	0.00
Mermiria bivittata	0.08	0.00
Pseudopomala brachyptera	0.06	1.50
Acrolophitus hirtipes	0.03	0.00
Aeoloplides turnbulli	0.03	0.00
Arphia conspera	0.03	0.00
Chorthippus curtipennis	0.03	0.00
Psoloessa delicatula	0.03	0.00
Spharagemon equale	0.03	0.00

[a] 3,548 and 466 insects collected at the *Nosema*–bait and control sites, respectively.

Table 10—Frequency of instars and adults of all grasshopper species combined on the pretreatment sampling date, 21 June 1987, at the Tobacco Garden block treated with *Nosema*–bait

Instar/Stage	Frequency (%)
1st	14.25
2d	20.33
3d	23.59
4th	21.50
5th	14.55
Adult	5.78

Table 11—Pretreatment densities of grasshoppers and percentage of change in densities at the Tobacco Garden block, 1987–89

Population variable	Grasshopper taxon	*Nosema*-bran bait[a]	Control[a]
Pretreatment density	All grasshoppers[b]	4.90 ± 0.820 (21)a	6.66 ± 1.554 (3)a
	Bran accepting	3.70 ± 1.025 (21)a	5.64 ± 1.443 (3)a
	Bran rejecting	0.59 ± 0.140 (21)a	0.54 ± 0.227 (3)a
	Bran vulnerable[b]	0.73 ± 0.202 (21)a	0.14 ± 0.120 (3)a
	M. infantilis	1.06 ± 0.191 (21)a	2.18 ± 1.249 (3)a
	A. deorum	1.06 ± 0.432 (21)a	0.22 ± 0.134 (3)a
	M. sanguinipes	0.90 ± 0.413 (21)a	0.83 ± 0.677 (3)a
% change (pre- to[c] 10-d posttreatment)	All grasshoppers[b]	–26.43 ± 12.568 (21)	–45.94 ± 9.897 (3)
	Bran accepting	–29.70 ± 12.051 (21)	–46.17 ± 15.926 (3)
% change (pre- to[c] average July 1987)	All grasshoppers[b]	–26.57 ± 13.085 (21)	–41.03 ± 9.009 (3)
	Bran accepting	–35.02 ± 8.794 (21)	–40.78 ± 16.322 (3)
% change (pre- to[c] average July 1988)	All grasshoppers[b]	–62.83 ± 5.760 (21)	–80.38 ± 4.845 (3)
	Bran accepting	–67.99 ± 5.209 (21)	–85.29 ± 4.461 (3)
% change (pre- to[c] average July 1989)	All grasshoppers[b]	–10.50 ± 33.798 (21)	–52.43 ± 22.853 (3)
	Bran accepting	–36.23 ± 22.274 (21)	–66.47 ± 15.431 (3)

[a] Values are means ± 1 SEM with sample sizes in parentheses. Means followed by the same letter within rows are not significantly different (Kruskal–Wallis test, $P > 0.05$).

[b] Does not include late-hatching species.

[c] Change in grasshopper densities between the pretreatment and average July 1987, 1988, and 1989 densities.

Table 12—Grasshopper species composition at the North River block on the pretreatment sample date, 13 June 1988

Species	% of total[a]	
	Bran-bait	Control
Camnula pellucida	33.24	9.09
Aeropedellus clavatus	19.72	15.91
Ageneotettix deorum	13.24	15.91
Melanoplus confusus	9.48	11.82
Melanoplus sanguinipes	6.86	4.09
Melanoplus infantilis	5.35	8.64
Phlibostroma quadrimaculatum	2.54	4.09
Amphitornus coloradus	1.97	5.00
Eritettix simplex	1.69	1.82
Trachyrhachys kiowa	1.41	11.82
Psoloessa delicatula	1.13	0.00
Melanoplus bivittatus	0.85	0.00
Opeia obscura	0.56	0.91
Melanoplus packardii	0.56	5.91
Encoptolophus costalis	0.56	0.00
Metator pardalinus	0.56	0.00
Dactylotum bicolor	0.28	0.00
Boopedon nubilum	0.00	2.73
Phoetaliotes nebrascensis	0.00	0.46
Pardalophora haldemanii	0.00	0.46
Aulocara femoratum	0.00	0.46
Hadrotettix trifasciatus	0.00	0.46
Mermiria bivittata	0.00	0.46

[a] 355 and 220 insects collected in the carbaryl–bran bait and control sites, respectively.

Table 13—Frequency of instars and adults of all grasshopper species combined on the pretreatment sampling dates for the three standard carbaryl–bran bait treatment experiments

Study	Instar/Stage	Frequency (%)
North River[a]	1st	0.31
	2d	4.04
	3d	12.58
	4th	20.96
	5th	22.05
	Adult	40.06
Elkhorn[b]	1st	0.94
	2d	4.22
	3d	17.63
	4th	22.72
	5th	24.73
	Adult	29.76
Antelope–Bran[c]	1st	0.94
	2d	4.22
	3d	17.63
	4th	22.72
	5th	24.73
	Adult	29.76

[a] Pretreatment date, 13 June 1988.
[b] Pretreatment date, 15 June 1988.
[c] Pretreatment date, 4 July 1991.

Table 14—Pretreatment densities of grasshoppers and percentage of change in densities, North River block, 1988–89

Population variable	Grasshopper taxon	Carbaryl–bran bait[a]	Control[a]
Pretreatment density	All grasshoppers[b]	5.54 ± 1.632 (9)a	1.56 ± 0.352 (10)b
	Bran accepting	4.24 ± 1.538 (9)a	0.82 ± 0.158 (10)b
	Bran rejecting	1.27 ± 0.541 (9)a	0.65 ± 0.275 (10)a
	Bran vulnerable[b]	0.01 ± 0.009 (9)a	0.03 ± 0.015 (10)a
	C. pellucida	2.16 ± 1.262 (9)a	0.11 ± 0.049 (10)a
	A. clavatus	0.99 ± 0.426 (9)a	0.30 ± 0.191 (10)a
	A. deorum	0.54 ± 0.107 (9)a	0.23 ± 0.084 (10)b
% change (pre- to 2-d posttreatment	All grasshoppers[b]	–35.99 ± 9.814 (9)	48.87 ± 21.581 (9)
	Bran accepting	–57.84 ± 5.678 (9)	124.99 ± 76.803 (9)
	C. pellucida	–76.10 ± 7.425 (5)	40.64 ± 90.274 (4)
% change (pre- to[c] July 1988)	All grasshoppers[b]	–72.24 ± 6.695 (9)	–38.00 ± 11.847 (9)
	Bran accepting	–83.80 ± 4.303 (9)	–24.02 ± 26.206 (9)
	C. pellucida	–89.68 ± 7.068 (5)	–25.68 ± 26.295 (4)
% change (pre- to[c] June 1989)	All grasshoppers[b]	–7.55 ± 32.341 (9)	71.16 ± 32.232 (9)
	Bran accepting	–73.63 ± 9.389 (9)	85.98 ± 67.723 (9)
	C. pellucida	–98.22 ± 0.848 (5)	–40.50 ± 16.557 (4)
% change (pre- to[c] July 1989)	All grasshoppers[b]	–30.79 ± 17.159 (9)	31.81 ± 21.660 (9)
	Bran accepting	–87.46 ± 4.830 (9)	34.18 ± 36.456 (9)
	C. pellucida	–97.99 ± 0.840 (5)	–51.44 ± 27.575 (4)

[a] Values are means ± 1 SEM with sample sizes in parentheses. Means followed by the same letter within rows are not significantly different (Kruskal–Wallis test, $P > 0.05$).

[b] Does not include late-hatching species.

[c] Change in grasshopper densities between the pretreatment and average July 1988, June 1989, and July 1989 densities.

Table 15—Grasshopper species composition at the Elkhorn block on the pretreatment sample date, 15 June 1988

Species	% of total[a]	
	Bran-bait	Control
Camnula pellucida	39.13	1.20
Aeropedellus clavatus	15.43	12.74
Melanoplus infantilis	11.15	8.17
Ageneotettix deorum	9.39	10.58
Melanoplus sanguinipes	9.29	4.33
Melanoplus confusus	6.78	6.49
Trachyrhachys kiowa	1.95	6.01
Aulocara elliotti	1.67	0.24
Eritettix simplex	1.58	6.25
Melanoplus packardii	0.74	1.20
Amphitornus coloradus	0.65	2.89
Psoloessa delicatula	0.65	3.61
Phlibostroma quadrimaculatum	0.56	24.76
Boopedon nubilum	0.19	2.89
Opeia obscura	0.09	3.13
Phoetaliotes nebrascensis	0.09	0.24
Pardalophora haldemanii	0.09	0.00
Aulocara femoratum	0.09	0.00
Acrolophitus hirtipes	0.09	0.48
Arphia conspersa	0.09	0.24
Melanoplus dawsonii	0.09	0.00
Xanthippus corallipes	0.09	0.00
Metator pardalinus	0.09	0.24
Mermiria bivittata	0.00	1.68
Encoptolophus costalis	0.00	1.20
Hesperotettix viridis	0.00	0.48
Hypochlora alba	0.00	0.48
Arphia pseudonietana	0.00	0.48

[a] 1,076 and 416 insects collected in the carbaryl–bran bait and control sites, respectively.

Table 16—Pretreatment densities of grasshoppers and percentage of change in densities, Elkhorn block, 1988–89

Population variable	Grasshopper taxon	Carbaryl–bran bait[a]	Control[a]
Pretreatment density	All grasshoppers[b]	5.05 ± 1.079 (10)a	2.66 ± 0.404 (10)a
	Bran accepting	3.91 ± 1.014 (10)a	1.13 ± 0.139 (10)b
	Bran rejecting	1.10 ± 0.282 (10)a	1.29 ± 0.272 (10)a
	Bran vulnerable[b]	0.15 ± 0.045 (10)a	0.44 ± 0.173 (10)a
	C. pellucida	1.66 ± 0.945 (10)a	0.04 ± 0.015 (10)a
	A. clavatus	0.89 ± 0.226 (10)a	0.39 ± 0.073 (10)a
	M. infantilis	0.68 ± 0.205 (10)a	0.29 ± 0.089 (10)a
% change (pre- to 1-d posttreatment	All grasshoppers[b]	–54.60 ± 7.870 (10)	–12.59 ± 11.144 (10)
	Bran accepting	–68.33 ± 5.043 (10)	15.62 ± 26.631 (10)
% change (pre- to[c] July 1988)	All grasshoppers[b]	–78.21 ± 4.073 (10)	–58.83 ± 6.586 (10)
	Bran accepting	–85.52 ± 3.246 (10)	–46.28 ± 13.108 (10)
% change (pre- to[c] June 1989)	All grasshoppers[b]	–43.24 ± 7.808 (10)	–10.35 ± 13.293 (10)
	Bran accepting	–65.14 ± 5.933 (10)	0.34 ± 17.611 (10)
% change (pre- to[c] July 1989)	All grasshoppers[b]	–21.04 ± 23.341 (10)	28.81 ± 18.958 (10)
	Bran accepting	–58.37 ± 12.659 (10)	–1.63 ± 15.901 (10)

[a] Values are means ± 1 SEM with sample sizes in parentheses. Means followed by the same letter within rows are not significantly different (Kruskal–Wallis test, $P > 0.05$).

[b] Does not include late-hatching species.

[c] Change in grasshopper densities between the pretreatment and average July 1988 and July 1989 densities.

Table 17—Grasshopper species composition at the Antelope–Bran block on the pretreatment sample date, 4 July 1991

Species	% of total[a]	
	Bran-bait	Control
Melanoplus infantilis	29.77	15.88
Melanoplus sanguinipes	18.37	27.08
Phoetaliotes nebrascensis	14.54	13.72
Melanoplus femurrubrum	7.16	7.22
Opeia obscura	4.01	0.00
Aulocara elliotti	3.72	0.00
Trachyrhachys kiowa	3.55	3.25
Ageneotettix deorum	3.49	0.00
Phlibostroma quadrimaculatum	3.49	6.86
Melanoplus packardii	3.32	7.58
Aeropedellus clavatus	1.60	2.53
Encoptolophus costalis	1.32	3.25
Camnula pellucida	1.03	9.03
Mermiria bivittata	0.86	0.36
Amphitornus coloradus	0.80	0.36
Arphia pseudonietana	0.63	0.00
Melanoplus dawsonii	0.46	1.81
Melanoplus tristis	0.46	0.00
Melanoplus bivittatus	0.40	0.00
Melanoplus confusus	0.23	0.00
Orphulella speciosa	0.23	0.00
Metator pardalinus	0.17	0.00
Hypochlora alba	0.17	0.36
Psoloessa delicatula	0.06	0.00
Boopedon nubilum	0.06	0.00
Melanoplus keeleri	0.06	0.00
Hesperotettix viridis	0.06	0.36
Eritettix simplex	0.00	0.36

[a] 1,747 and 277 insects collected at the carbaryl–bran bait and control sites, respectively.

Table 18—Pretreatment densities of grasshoppers and percentage of change in densities, Antelope–Bran block, 1991–92

Population variable	Grasshopper taxon	Carbaryl–bran bait[a]	Control[a]
Pretreatment density	All grasshoppers[b]	20.90 ± 5.583 (8)a	13.33 ± 7.436 (3)a
	Bran accepting	12.13 ± 3.928 (8)a	7.94 ± 4.938 (3)a
	Bran rejecting	1.66 ± 0.499 (8)a	1.69 ± 1.125 (3)a
	Bran vulnerable[b]	6.50 ± 2.725 (8)a	3.25 ± 1.627 (3)a
	M. infantilis	5.32 ± 2.147 (8)a	1.80 ± 1.652 (3)a
	M. sanguinipes	3.89 ± 1.340 (8)a	3.38 ± 2.416 (3)a
	P. nebrascensis	3.81 ± 1.495 (8)a	1.98 ± 1.047 (3)a
% change (pre- to 4-d posttreatment	All grasshoppers[b]	–17.39 ± 13.298 (8)	26.20 ± 33.420 (3)
	Bran accepting	–8.22 ± 20.852 (8)	23.58 ± 23.594 (3)
	Bran vulnerable[b]	–35.73 ± 13.087 (6)	29.10 ± 48.914 (2)
	M. infantilis	–38.26 ± 16.527 (7)	27.55 ± 55.731 (2)
	M. sanguinipes	–14.54 ± 21.910 (8)	4.95 ± 0.219 (3)
	P. nebrascensis	–41.42 ± 23.339 (6)	6.89 ± 61.065 (2)
% change (pre- to[c] July 1991)	All grasshoppers[b]	–43.73 ± 7.949 (8)	26.88 ± 30.060 (3)
	Bran accepting	–34.15 ± 15.306 (8)	11.19 ± 25.509 (3)
	Bran vulnerable[b]	–67.26 ± 5.816 (6)	55.38 ± 78.628 (2)
	M. infantilis	–40.31 ± 11.253 (7)	42.27 ± 64.183 (2)
	M. sanguinipes	–44.63 ± 16.039 (8)	–27.07 ± 6.495 (2)
	P. nebrascensis	–70.32 ± 6.941 (6)	87.39 ± 73.884 (2)
% change (pre- to[c] June 1992)	All grasshoppers[b]	–72.94 ± 5.669 (8)	–65.02 ± 3.837 (3)
	Bran accepting	–59.53 ± 7.779 (8)	–55.73 ± 8.435 (3)
	Bran vulnerable[b]	–93.92 ± 1.889 (6)	–60.63 ± 33.448 (2)
	M. infantilis	–71.23 ± 8.634 (7)	–53.15 ± 5.885 (2)
	M. sanguinipes	–67.91 ± 15.110 (8)	–82.71 ± 7.469 (2)
	P. nebrascensis	–93.72 ± 1.578 (6)	–47.37 ± 44.976 (2)
% change (pre- to[c] July 1992)	All grasshoppers[b]	–58.32 ± 7.425 (8)	–14.85 ± 28.472 (3)
	Bran accepting	–54.58 ± 10.766 (8)	28.84 ± 93.774 (3)
	Bran vulnerable[b]	–70.47 ± 8.613 (6)	–15.46 ± 51.454 (2)
	M. infantilis	–65.53 ± 9.569 (7)	–43.99 ± 23.731 (2)
	M. sanguinipes	–55.02 ± 15.744 (8)	–26.26 ± 15.635 (2)
	P. nebrascensis	–73.57 ± 6.974 (6)	–2.48 ± 40.891 (2)

[a] Values are means ± 1 SEM with sample sizes in parentheses. Means followed by the same letter within rows are not significantly different (Kruskal–Wallis test, $P > 0.05$).
[b] Does not include late-hatching species.
[c] Change in grasshopper densities between the pretreatment and average July 1991, June 1992, and July 1992 densities.

Table 19—Grasshopper species composition at the malathion-treated Sather Lake block on the pretreatment sample date, 4 July 1987, and at the untreated North River block on 23 June 1987

Species	% of total[a]	
	Sather Lake	North River
Ageneotettix deorum	26.21	15.02
Melanoplus sanguinipes	20.66	22.38
Melanoplus infantilis	14.64	5.93
Aulocara elliotti	9.77	2.08
Trachyrhachys kiowa	5.47	5.78
Amphitornus coloradus	4.61	5.65
Camnula pellucida	4.02	7.95
Aeropedellus clavatus	3.15	1.84
Opeia obscura	3.01	8.33
Melanoplus packardii	2.08	2.03
Phlibostroma quadrimaculatum	1.31	2.68
Melanoplus bivittatus	1.20	4.31
Melanoplus confusus	0.68	1.68
Melanoplus sp.	0.66	0.25
Aulocara femoratum	0.58	2.40
Orphulella speciosa	0.38	1.86
Phoetaliotes nebrascensis	0.36	3.00
Hesperotettix viridus	0.27	1.35
Melanoplus gladstoni	0.16	0.00
Psoloessa delicatula	0.14	0.26
Eritettix simplex	0.14	0.31
Unknown Oedipodinae	0.14	0.00
Metator pardalinus	0.08	1.38
Mermiria bivittata	0.06	0.45
Melanoplus dawsonii	0.06	0.51
Melanoplus bowditchi	0.06	0.23
Unknown Gomphocerinae	0.03	0.07
Melanoplus flavidus	0.03	0.00
Encoptolophus costalis	0.03	0.00
Boopedon nubilum	0.00	0.92
Melanoplus femurrubrum	0.00	0.59
Melanoplus keeleri	0.00	0.26
Derotmema haydeni	0.00	0.13
Dissosteira carolina	0.00	0.12
Aeoloplides turnbulli	0.00	0.12
Pseudopomala brachyptera	0.00	0.03
Chorthippus curtipennis	0.00	0.03
Chloealtis conspersa	0.00	0.03
Hypochlora alba	0.00	0.02
Arphia pseudonietana	0.00	0.02

[a] 3,655 and 6,073 insects collected at the Sather Lake and North River blocks, respectively.

Table 20—Frequency of instars and adults of all grasshopper species combined on the pretreatment sampling dates for the four standard malathion spray treatment studies

Study	Instar/Stage	Frequency (%)
Sather Lake[a]	1st	0.30
	2d	0.63
	3d	3.89
	4th	10.67
	5th	30.07
	Adult	54.45
Redwing Creek[b]	1st	1.68
	2d	4.14
	3d	13.99
	4th	37.21
	5th	29.95
	Adult	13.03
Cherry Creek[c]	1st	0.07
	2d	2.80
	3d	10.63
	4th	26.96
	5th	43.75
	Adult	15.80
Charlie Creek[d]	1st	1.08
	2d	2.54
	3d	9.83
	4th	25.90
	5th	47.21
	Adult	12.97

[a] Pretreatment date, 4 July 1987.
[b] Pretreatment date, 1 July 1990.
[c] Pretreatment date, 4 July 1990.
[d] Pretreatment date, 14 July 1992.

Table 21—Pretreatment densities of grasshoppers and percentage of change in densities, Sather Lake and North River blocks, 1987

Population variable	Grasshopper taxon	Sather Lake[ab]	North River[ab]
Pretreatment density	All grasshoppers[c]	9.24 ± 0.984 (29)a	9.89 ± 1.175 (41)a
	A. deorum	2.44 ± 0.400 (29)a	1.37 ± 0.188 (41)b
	M. sanguinipes	1.99 ± 0.224 (29)a	2.28 ± 0.285 (41)a
	M. infantilis	1.43 ± 0.266 (29)a	0.64 ± 0.104 (41)b
% change (pre- to 2-d posttreatment	All grasshoppers[c]	–94.06 ± 1.127 (29)	24.13 ± 14.240 (39)
	A. deorum	–92.18 ± 2.268 (28)	37.52 ± 38.628 (39)
	M. sanguinipes	–91.71 ± 2.278 (29)	30.80 ± 24.992 (38)
% change (pre- to[d] July 1987)	All grasshoppers[c]	–90.20 ± 1.222 (29)	–14.72 ± 7.534 (41)
	A. deorum	–80.72 ± 8.052 (28)	54.65 ± 38.469 (41)
	M. sanguinipes	–92.51 ± 1.315 (29)	–8.92 ± 17.674 (40)

[a] Sather Lake block was treated with malathion; North River block was not treated in 1987.

[b] Values are means ± 1 SEM with sample sizes in parentheses. Means followed by the same letter within rows are not significantly different (Kruskal–Wallis test, $P > 0.05$).

[c] Does not include late-hatching species.

[d] Change in grasshopper densities between the pretreatment and average July 1987 densities.

Table 22—Grasshopper species composition at the Redwing Creek block on the pretreatment sample date, 1 July 1990

Species	% of total[a]	
	Malathion	Control
Melanoplus infantilis	20.55	20.50
Trachyrhachys kiowa	17.44	10.41
Aulocara elliotti	12.82	18.18
Ageneotettix deorum	9.80	10.08
Camnula pellucida	7.16	1.65
Melanoplus sanguinipes	6.97	8.10
Amphitornus coloradus	6.50	10.41
Aeropedellus clavatus	6.13	1.82
Phlibostroma quadrimaculatum	5.18	14.05
Melanoplus confusus	1.98	2.15
Melanoplus gladstoni	1.60	0.00
Psoloessa delicatula	1.32	0.66
Opeia obscura	0.85	0.00
Melanoplus packardii	0.66	0.33
Eritettix simplex	0.38	0.33
Hesperotettix viridus	0.19	0.66
Chortophaga viridifasciatus	0.19	0.00
Xanthippus corallipes	0.09	0.00
Metator pardalinus	0.09	0.00
Arphia conspersa	0.09	0.00
Melanoplus dawsonii	0.00	0.33
Melanoplus keeleri	0.00	0.17
Melanoplus bivittatus	0.00	0.17

[a] 1,061 and 605 insects collected at the malathion and control sites, respectively.

Table 23—Pretreatment densities of grasshoppers and percentage of change in densities, Redwing Creek block, 1990–91

Population variable	Grasshopper taxon	Malathion[a]	Control[a]
Pretreatment density	All grasshoppers[b]	11.17 ± 2.888 (10)a	6.78 ± 2.658 (10)b
	M. infantilis	2.55 ± 0.658 (10)a	1.25 ± 0.233 (10)a
	T. kiowa	1.73 ± 0.986 (10)a	0.65 ± 0.238 (10)a
	A. elliotti	1.26 ± 0.759 (10)a	1.52 ± 1.364 (10)a
	A. deorum	1.12 ± 0.316 (10)a	0.67 ± 0.295 (10)a
% change (pre- to 3-d posttreatment	All grasshoppers[b]	–91.04 ± 3.240 (10)	18.85 ± 13.982 (10)
	M. infantilis	–88.30 ± 9.955 (9)	–51.39 ± 13.780 (8)
% change (pre- to[c] July 1990)	All grasshoppers[b]	–91.49 ± 2.747 (10)	31.98 ± 19.804 (10)
	M. infantilis	–88.41 ± 9.928 (10)	–28.52 ± 12.002 (9)
% change (pre- to[c] July 1991)	All grasshoppers[b]	–83.55 ± 3.860 (10)	–33.27 ± 24.839 (10)
	M. infantilis	–90.94 ± 2.519 (9)	–74.69 ± 11.164 (9)

[a] Values are means ± 1 SEM with sample sizes in parentheses. Means followed by the same letter within rows are not significantly different (Kruskal–Wallis test, $P > 0.05$).
[b] Does not include late-hatching species.
[c] Change in grasshopper densities between the pretreatment and average July 1990 and July 1991 densities.

Table 24—Grasshopper species composition at the Cherry Creek block on the pretreatment sample date, 4 July 1990

Species	% of total[a]	
	Malathion	Control
Melanoplus infantilis	28.33	19.25
Melanoplus sanguinipes	17.37	18.36
Ageneotettix deorum	13.16	11.82
Phlibostroma quadrimaculatum	6.84	5.82
Trachyrhachys kiowa	6.40	2.46
Melanoplus packardii	5.35	1.49
Melanoplus confusus	4.12	1.66
Opeia obscura	3.68	2.02
Chortophaga viridifasciatus	2.54	0.30
Aeropedellus clavatus	2.46	0.95
Aulocara elliotti	1.84	9.74
Melanoplus flavidus Scudder	1.23	0.65
Amphitornus coloradus	0.79	2.26
Orphulella speciosa	0.79	0.30
Eritettix simplex	0.79	0.12
Melanoplus dawsonii	0.70	1.72
Phoetaliotes nebrascensis	0.53	0.42
Melanoplus keeleri	0.53	0.00
Encoptolophus costalis	0.44	0.06
Melanoplus bivittatus	0.35	0.65
Psoloessa delicatula	0.35	0.00
Metator pardalinus	0.26	0.18
Camnula pellucida	0.26	1.07
Dissosteira carolina	0.26	0.00
Mermiria bivittata	0.18	0.06
Spharagemon collare	0.18	0.00
Arphia pseudonietana	0.09	0.18
Pardalophora haldemanii	0.09	0.00
Unknown Oedipodinae	0.09	0.00
Melanoplus femurrubrum	0.00	17.65
Boopedon nubilum	0.00	0.48
Aeoloplides tenuipennis	0.00	0.12
Acrolophitus hirtipes	0.00	0.06

[a] 1,140 and 1,683 insects collected in the malathion and control sites, respectively.

Table 25—Pretreatment densities of grasshoppers and percentage of change in densities, Cherry Creek block, 1990–91

Population variable	Grasshopper taxon	Malathion[a]	Control[a]
Pretreatment density	All grasshoppers[b]	9.89 ± 1.782 (10)a	12.78 ± 3.360 (10)a
	M. infantilis	2.75 ± 0.597 (10)a	2.52 ± 0.851 (10)a
	M. sanguinipes	1.87 ± 0.524 (10)a	2.69 ± 0.673 (10)a
	A. deorum	1.26 ± 0.434 (10)a	1.27 ± 0.653 (10)a
% change (pre- to 3-d posttreatment	All grasshoppers[b]	–88.10 ± 3.973 (10)	–19.10 ± 16.647 (10)
	M. infantilis	–98.17 ± 1.089 (10)	–58.10 ± 13.337 (10)
% change (pre- to[c] July 1990)	All grasshoppers[b]	–91.20 ± 2.824 (10)	–3.16 ± 22.946 (10)
	M. infantilis	–94.97 ± 3.047 (10)	–75.40 ± 6.133 (10)
% change (pre- to[c] July 1991)	All grasshoppers[b]	–69.49 ± 5.188 (10)	19.96 ± 44.906 (9)
	M. infantilis	–68.51 ± 15.099 (10)	–62.49 ± 16.437 (9)

[a] Values are means ± 1 SEM with sample sizes in parentheses. Means followed by the same letter within rows are not significantly different (Kruskal–Wallis test, $P > 0.05$).

[b] Does not include late-hatching species.

[c] Change in grasshopper densities between the pretreatment and average July 1990 and July 1991 densities.

Table 26—Grasshopper species composition at the Charlie Creek block on the pretreatment sample date, 17 July 1992

Species	% of total[a]	
	Malathion	Control
Melanoplus infantilis	42.66	11.68
Melanoplus sanguinipes	29.23	23.31
Ageneotettix deorum	11.49	21.50
Trachyrhachys kiowa	4.53	1.36
Melanoplus femurrubrum	1.35	3.17
Melanoplus packardii	1.29	9.99
Hypochlora alba	1.13	0.14
Arphia pseudonietana	1.08	0.00
Opeia obscura	1.02	2.74
Amphitornus coloradus	0.86	0.99
Phlibostroma quadrimaculatum	0.81	9.02
Melanoplus gladstoni	0.81	1.87
Aeropedellus clavatus	0.81	0.28
Encoptolophus costalis	0.65	0.40
Melanoplus dawsonii	0.59	3.76
Orphulella speciosa	0.49	0.14
Camnula pellucida	0.32	1.53
Spharagemon collare	0.16	1.30
Melanoplus confusus	0.16	0.48
Phoetaliotes nebrascensis	0.11	0.59
Metator pardalinus	0.11	0.51
Melanoplus bivittatus	0.11	0.20
Aulocara elliotti	0.05	3.37
Aulocara femoratum	0.05	0.08
Eritettix simplex	0.05	0.03
Spharagemon equale	0.05	0.00
Chorthippus curtipennis	0.00	0.45
Dissosteira carolina	0.00	0.28
Hesperotettix viridus	0.00	0.23
Hadrotettix trifasciatus	0.00	0.17
Xanthippus corallipes	0.00	0.14
Melanoplus keeleri	0.00	0.14
Unknown Oedipodinae	0.00	0.08
Arphia conspersa	0.00	0.03
Aeoloplides tenuipennis	0.00	0.03

[a] 1,854 and 3,535 insects in the malathion and control sites, respectively.

Table 27—Pretreatment densities of grasshoppers and percentage of change in densities, Charlie Creek block, 1992–93

Population variable	Grasshopper taxon	Malathion[a]	Control[a]
Pretreatment density	All grasshoppers[b]	15.78 ± 1.682 (10)a	20.87 ± 3.644 (9)a
	M. infantilis	6.62 ± 1.112 (10)a	2.53 ± 1.521 (9)b
	M. sanguinipes	4.42 ± 0.886 (10)a	5.67 ± 0.752 (9)a
	A. deorum	1.97 ± 0.406 (10)a	3.54 ± 1.635 (9)a
% change (pre- to 3-d posttreatment	All grasshoppers[b]	–98.51 ± 0.745 (10)	–23.86 ± 7.697 (9)
	M. infantilis	–99.90 ± 0.097 (10)	–13.49 ± 21.045 (9)
	M. sanguinipes	–96.26 ± 1.859 (10)	–12.55 ± 22.228 (9)
	A. deorum	–88.84 ± 9.891 (10)	–38.23 ± 13.952 (9)
% change (pre- to[c] July 1993)	All grasshoppers[b]	–86.33 ± 1.827 (10)	–37.03 ± 16.135 (9)
	M. infantilis	–96.27 ± 0.718 (10)	31.95 ± 43.936 (7)
	M. sanguinipes	–50.53 ± 11.858 (10)	–11.39 ± 26.200 (9)
	A. deorum	–99.40 ± 0.231 (9)	–54.96 ± 15.391 (9)

[a] Values are means ± 1 SEM with sample sizes in parentheses. Means followed by the same letter within rows are not significantly different (Kruskal–Wallis test, $P > 0.05$).

[b] Does not include late-hatching species.

[c] Change in grasshopper densities between the pretreatment and average July 1993 densities.

Table 28–Grasshopper species composition at the Antelope–74 block on the pretreatment sample date, 4 July 1991

Species	% of total[a]	
	Carbaryl	Control
Melanoplus infantilis	36.32	26.28
Phoetaliotes nebrascensis	7.97	5.25
Camnula pellucida	7.31	17.97
Melanoplus sanguinipes	6.94	17.80
Encoptolophus costalis	6.37	0.95
Phlibostroma quadrimaculatum	6.05	2.68
Trachyrhachys kiowa	5.20	3.07
Ageneotettix deorum	5.11	6.31
Opeia obscura	3.61	1.90
Arphia pseudonietana	2.34	0.39
Melanoplus dawsonii	2.25	7.09
Melanoplus packardii	1.92	1.34
Aeropedellus clavatus	1.69	2.46
Aulocara elliotti	1.69	0.39
Orphulella speciosa	1.31	0.11
Hypochlora alba	1.22	0.45
Melanoplus gladstoni	0.84	0.00
Melanoplus keeleri	0.70	0.11
Hesperotettix viridis	0.52	0.28
Melanoplus femurrubrum	0.33	3.46
Melanoplus confusus	0.23	0.39
Amphitornus coloradus	0.05	0.11
Eritettix simplex	0.05	0.06
Melanoplus bivittatus	0.00	0.78
Metator pardalinus	0.00	0.17
Arphia conspersa	0.00	0.11
Psoloessa delicatula	0.00	0.06
Chorthippus curtipennis	0.00	0.06

[a] 2,134 and 1,792 insects collected at the carbaryl and control sites, respectively.

Table 29–Frequency of instars and adults of all grasshopper species combined on the pretreatment sampling date at sites within the Antelope–74 and Johnson Ranch blocks treated with standard carbaryl sprays.

Study	Instar/Stage	Frequency (%)
Antelope–74[a]	1st	0.61
	2d	5.48
	3d	12.07
	4th	26.06
	5th	36.55
	Adult	19.23
Johnson Ranch[b]	1st	11.07
	2d	35.90
	3d	34.03
	4th	12.79
	5th	5.16
	Adult	1.05

[a] Pretreatment date, 4 July 1991.
[b] Pretreatment date, 12 July 1993.

Table 30–Pretreatment densities of grasshoppers and percentage of change in densities, Antelope–74 block, 1991–92

Population variable	Grasshopper taxon	Carbaryl[a]	Control[a]
Pretreatment density	All grasshoppers[b]	15.79 ± 4.756 (10)a	18.22 ± 4.737 (10)a
	M. infantilis	5.37 ± 2.006 (10)a	5.73 ± 1.333 (10)a
% change (pre- to 2-d posttreatment	All grasshoppers[b]	–94.04 ± 1.903 (10)	–31.01 ± 7.747 (10)
	M. infantilis	–94.73 ± 2.090 (10)	–46.33 ± 9.222 (8)
% change (pre- to[c] July 1991)	All grasshoppers[b]	–91.70 ± 2.000 (10)	–25.17 ± 12.943 (10)
	M. infantilis	–97.19 ± 1.318 (10)	–51.91 ± 10.355 (8)
% change (pre- to[c] July 1992)	All grasshoppers[b]	–87.20 ± 5.363 (10)	–48.39 ± 14.152 (10)
	M. infantilis	–86.11 ± 9.333 (10)	–81.60 ± 5.309 (8)

[a] Values are means ± 1 SEM with sample sizes in parentheses. Means followed by the same letter within rows are not significantly different (Kruskal–Wallis test, $P > 0.05$).
[b] Does not include late-hatching species.
[c] Change in grasshopper densities between the pretreatment and average July 1991 and July 1992 densities.

Table 31–Grasshopper species composition at the Johnson Ranch block on the pretreatment sample date, 12 July 1993

Species	% of total[a]	
	Carbaryl	Control
Melanoplus sanguinipes	45.32	44.00
Melanoplus infantilis	8.74	8.76
Melanoplus gladstoni	7.02	2.67
Ageneotettix deorum	5.79	16.95
Phlibostroma quadrimaculatum	4.68	1.33
Opeia obscura	4.68	1.52
Melanoplus packardii	4.19	2.67
Melanoplus femurrubrum	4.06	1.33
Encoptolophus costalis	3.20	2.86
Trachyrhachys kiowa	2.71	2.10
Melanoplus bivittatus	2.46	0.38
Camnula pellucida	1.72	0.00
Phoetaliotes nebrascensis	1.36	8.57
Melanoplus keeleri	1.23	1.14
Arphia pseudonietana	0.99	0.19
Boopedon nubilum	0.37	0.00
Aeropedellus clavatus	0.25	1.33
Hypochlora alba	0.25	0.38
Melanoplus dawsonii	0.12	0.57
Aulocara elliotti	0.12	0.76
Orphulella speciosa	0.12	0.00
Amphitornus coloradus	0.12	1.71
Unknown Oedipodinae	0.12	0.00
Mermiria bivittata	0.12	0.19
Hadrotettix trifasciatus	0.12	0.00
Chortophaga viridifasciatus	0.12	0.00
Melanoplus confusus	0.00	0.38
Arphia conspersa	0.00	0.19

[a] 812 and 525 insects collected at the carbaryl and control sites, respectively.

Table 32–Pretreatment densities of grasshoppers and percentage of change in densities, Johnson Ranch block, 1993

Population variable	Grasshopper taxon	Carbaryl[a]	Control[a]
Pretreatment density	All grasshoppers[b]	3.75 ± 0.781 (10)a	2.39 ± 0.359 (9)a
	M. sanguinipes	1.52 ± 0.378 (10)a	0.95 ± 0.215 (9)a
% change (pre- to 2-d posttreatment	All grasshoppers[b]	–83.96 ± 6.436 (10)	71.85 ± 41.831 (9)
% change (pre- to[c] July 1993)	All grasshoppers[b]	–86.88 ± 4.731 (10)	33.89 ± 26.455 (9)

[a] Values are means ± 1 SEM with sample sizes in parentheses. Means followed by the same letter within rows are not significantly different (Kruskal–Wallis test, $P > 0.05$).
[b] Does not include late-hatching species.
[c] Change in grasshopper densities between the pretreatment and average July 1993 densities.

Table 33–Grasshopper species composition at the McNany block on the pretreatment sample date, 29 June 1988

	% of total[a]	
Species	Malathion	Control
Camnula pellucida	45.54	23.08
Aulocara elliotti	27.43	27.47
Aeropedellus clavatus	7.61	15.39
Melanoplus sanguinipes	4.86	6.59
Ageneotettix deorum	4.07	2.20
Melanoplus confusus	3.68	8.79
Melanoplus infantilis	3.02	3.30
Melanoplus packardii	1.97	1.10
Melanoplus bivittatus	0.92	1.10
Hesperotettix viridis	0.39	1.10
Amphitornus coloradus	0.13	6.59
Aeoloplides turnbulli	0.13	0.00
Melanoplus femurrubrum	0.13	0.00
Melanoplus occidentalis	0.13	0.00
Metator pardalinus	0.00	2.20
Aulocara femoratum	0.00	1.10

[a] 762 and 91 insects collected in the malathion and control sites, respectively.

Table 34–Frequency of instars and adults of all grasshopper species combined on the pretreatment sampling dates at the three malathion hot spot treatment studies

Study	Instar/Stage	Frequency (%)
McNany[a]	1st	0.00
	2d	0.00
	3d	0.12
	4th	1.06
	5th	5.51
	Adult	93.32
Blue Butte[b]	1st	0.48
	2d	1.85
	3d	2.49
	4th	5.15
	5th	19.39
	Adult	70.62
Hovet[c]	1st	0.00
	2d	2.94
	3d	19.68
	4th	36.88
	5th	36.21
	Adult	4.29

[a] Pretreatment date, 29 June 1988.
[b] Pretreatment date, 18 July 1989.
[c] Pretreatment date, 25 June 1991.

Table 35–Pretreatment densities and percentage of change in densities of grasshoppers, McNany block, 1988–89

Population variable	Grasshopper taxon	Malathion[a]	Control[a]
Pretreatment density	All grasshoppers[b]	21.19 ± 4.170 (4)a	6.31 ± 4.864 (4)b
	C. pellucida	9.20 ± 4.434 (4)a	1.28 ± 0.914 (4)a
	A. elliotti	5.88 ± 1.991 (4)a	1.32 ± 0.894 (4)b
% change (pre- to to 1-d posttreatment	All grasshoppers[b]	–94.91 ± 1.914 (4)	145.25 ± 75.135 (4)
	C. pellucida	–98.53 ± 1.165 (4)	47.99 ± 85.458 (4)
	A. elliotti	–99.74 ± 0.166 (4)	21.54 ± 54.478 (4)
% change (pre- to[c] July 1988)	All grasshoppers[b]	–92.72 ± 2.005 (4)	21.88 ± 43.402 (4)
	C. pellucida	–78.09 ± 18.892 (4)	–44.50 ± 26.021 (4)
	A. elliotti	–99.43 ± 0.199 (4)	–51.82 ± 17.092 (4)
% change (pre- to[c] June 1989)	All grasshoppers[b]	–49.24 ± 15.844 (3)	101.91 ± 72.178 (4)
	C. pellucida	–100.00 ± 0.000 (4)	–97.63 ± 2.368 (4)
	A. elliotti	–33.58 ± 10.212 (3)	3.40 ± 59.424 (4)
% change (pre- to[c] July 1989)	All grasshoppers[b]	–82.83 ± 6.625 (4)	143.01 ± 99.476 (4)
	C. pellucida	–96.19 ± 2.987 (4)	–86.34 ± 12.148 (4)
	A. elliotti	–73.78 ± 3.456 (3)	–46.64 ± 18.808 (4)

[a] Values are means ± 1 SEM with sample sizes in parentheses. Means followed by the same letter within rows are not significantly different (Kruskal–Wallis test, $P > 0.05$).

[b] Does not include late-hatching species.

[c] Change in grasshopper densities between the pretreatment and average July 1988, June 1989, and July 1989 densities.

Table 36--Grasshopper species composition at the Blue Buttes block on the pretreatment sample date, 18 July 1989

Species	% of total[a]	
	Malathion	Control
Camnula pellucida	30.59	1.72
Ageneotettix deorum	28.32	23.89
Phlibostroma quadrimaculatum	14.34	4.93
Aeropedellus clavatus	6.81	9.85
Melanoplus sanguinipes	5.14	4.19
Melanoplus infantilis	2.87	15.52
Melanoplus keeleri	2.27	1.72
Opeia obscura	2.27	10.84
Aulocara elliotti	1.67	0.49
Trachyrhachys kiowa	1.08	12.56
Encoptolophus costalis	0.84	0.99
Metator pardalinus	0.72	1.23
Melanoplus packardii	0.72	0.49
Melanoplus dawsonii	0.60	0.00
Hesperotettix viridis	0.60	0.74
Melanoplus confusus	0.36	0.99
Hypochlora alba	0.24	0.49
Melanoplus bivittatus	0.24	0.74
Amphitornus coloradus	0.12	0.25
Aulocara femoratum	0.12	0.00
Orphulella speciosa	0.12	0.00
Melanoplus femurrubrum	0.00	2.71
Melanoplus gladstoni	0.00	2.22
Phoetaliotes nebrascensis	0.00	1.72
Arphia pseudonietana	0.00	1.23
Chorthippus curtipennis	0.00	0.25
Eritettix simplex	0.00	0.25

[a] 837 and 406 insects collected in the malathion and control sites, respectively.

Table 37–Pretreatment densities and percentage of change in densities of grasshoppers, Blue Butte block, 1989–90

Population variable	Grasshopper taxon	Malathion[a]	Control[a]
Pretreatment density	All grasshoppers[b]	19.21 ± 2.210 (6)a	4.22 ± 0.951 (6)b
	C. pellucida	6.33 ± 3.928 (6)a	0.07 ± 0.032 (6)b
	A. deorum	5.55 ± 2.229 (6)a	0.96 ± 0.573 (6)a
	P. quadrimaculatum	2.77 ± 2.035 (6)a	0.29 ± 0.258 (6)a
% change (pre- to to 2-d posttreatment	All grasshoppers[b]	–98.18 ± 4.268 (6)	11.17 ± 21.659 (6)
	C. pellucida	–99.14 ± 0.572 (6)	–24.45 ± 75.554 (4)
	A. deorum	–96.89 ± 2.727 (6)	15.30 ± 59.776 (6)
	P. quadrimaculatum	–99.28 ± 0.721 (2)	35.82 ± 135.821 (2)
% change (pre- to[c] June 1990)	All grasshoppers[b]	–71.00 ± 5.678 (6)	105.92 ± 36.316 (6)
	C. pellucida	–31.86 ± 27.517 (6)	555.99 ± 300.802 (4)
	A. deorum	–94.41 ± 1.729 (6)	165.73 ± 66.843 (6)
	P. quadrimaculatum	–100.00 ± 0.000 (2)	–95.66 ± 4.336 (2)
% change (pre- to[c] July 1990)	All grasshoppers[b]	–38.21 ± 12.886 (6)	220.44 ± 51.887 (6)
	C. pellucida	88.55 ± 76.824 (6)	416.01 ± 220.624 (4)
	A. deorum	–85.53 ± 6.956 (6)	107.64 ± 56.555 (6)
	P. quadrimaculatum	–98.49 ± 1.514 (2)	–4.32 ± 90.307 (2)

[a] Values are means ± 1 SEM with sample sizes in parentheses. Means followed by the same letter within rows are not significantly different (Kruskal–Wallis test, $P > 0.05$).
[b] Does not include late-hatching species.
[c] Change in grasshopper densities between the pretreatment and average June and July 1990 densities.

Table 38–Grasshopper species composition at the Hovet block on the pretreatment sample date, 25 June 1991

Species	% of total[a]	
	Malathion	Control
Camnula pellucida	30.79	0.00
Aulocara elliotti	21.26	14.71
Melanoplus infantilis	11.48	13.77
Phlibostroma quadrimaculatum	10.26	28.48
Melanoplus sanguinipes	6.66	11.74
Amphitornus coloradus	3.67	2.43
Ageneotettix deorum	3.42	5.13
Melanoplus femurrubrum	2.99	0.00
Aeropedellus clavatus	2.08	1.75
Trachyrhachys kiowa	1.89	5.94
Melanoplus confusus	1.77	2.83
Melanoplus bivittatus	1.47	0.68
Melanoplus packardii	1.34	5.80
Opeia obscura	0.61	0.00
Mermiria bivittata	0.12	2.70
Spharagemon equale	0.06	0.00
Hadrotettix trifasciatus	0.06	0.00
Eritettix simplex	0.06	0.41
Boopedon nubilum	0.00	2.16
Melanoplus keeleri	0.00	0.81
Hesperotettix viridis	0.00	0.41
Arphia conspersa	0.00	0.14
Hypochlora alba	0.00	0.14

[a] 1,637 and 741 insects collected in the malathion and control sites, respectively.

Table 39–Pretreatment densities and percentage of change in densities of grasshoppers, Hovet block, 1991–92

Population variable	Grasshopper	Malathion[a]	Control[a]
Pretreatment density	All grasshoppers[b]	38.80 ± 9.832 (5)a	25.72 ± 13.711 (5)a
	C. pellucida	10.08 ± 8.907 (5)a	0.00 ± 0.000 (5)b
	A. elliotti	8.10 ± 6.621 (5)a	5.49 ± 5.252 (5)a
	P. quadrimaculatum	4.86 ± 2.811 (5)a	7.77 ± 3.520 (5)a
	M. infantilis	4.78 ± 1.184 (5)a	2.87 ± 1.808 (5)a
% change (pre- to 2-d posttreatment)	All grasshoppers[b]	–91.56 ± 2.304 (5)	–68.93 ± 9.792 (5)
	C. pellucida	–74.14 ± 13.259 (3)	-
	A. elliotti	–92.10 ± 1.698 (3)	–43.27 ± 48.216 (4)
	P. quadrimaculatum	–91.36 ± 5.650 (3)	–52.12 ± 10.993 (5)
	M. infantilis	–97.92 ± 0.988 (5)	–71.93 ± 10.004 (4)
% change (pre- to[c] July 1991)	All grasshoppers[b]	–92.61 ± 1.460 (5)	–7.04 ± 50.555 (5)
	C. pellucida	–96.45 ± 0.389 (3)	-
	A. elliotti	–92.35 ± 0.872 (3)	18.45 ± 74.420 (4)
	P. quadrimaculatum	–87.30 ± 9.684 (3)	147.11 ± 155.065 (5)
	M. infantilis	–98.87 ± 0.496 (5)	–76.67 ± 7.548 (4)
% change (pre- to[c] July 1992)	All grasshoppers[b]	–82.31 ± 2.158 (5)	–39.92 ± 17.925 (5)
	C. pellucida	–93.74 ± 0.529 (3)	-
	A. elliotti	–94.04 ± 2.846 (3)	–88.41 ± 4.563 (4)
	P. quadrimaculatum	–95.92 ± 2.529 (3)	–68.26 ± 3.454 (5)
	M. infantilis	–68.84 ± 10.386 (5)	–34.90 ± 14.562 (4)

[a] Values are means ± 1 SEM with sample sizes in parentheses. Means followed by the same letter within rows are not significantly different (Kruskal–Wallis test, $P > 0.05$).
[b] Does not include late-hatching species.
[c] Change in grasshopper densities between the pretreatment and average July 1991 and July 1992 densities.

Table 40–Grasshopper species composition at the Tobacco Garden–Bran block on the pretreatment sample dates, 8 and 13 July 1990

	% of total			
	8 July 1990[a]		13 July 1990[b]	
Species	Bran-bait	Control	Bran-bait	Control
Camnula pellucida	30.16	7.40	18.68	14.82
Melanoplus infantilis	14.58	8.08	15.28	11.57
Melanoplus sanguinipes	14.45	10.13	15.47	14.82
Ageneotettix deorum	9.52	7.30	6.79	6.48
Melanoplus bivittatus	7.52	3.41	4.91	1.39
Phoetaliotes nebrascensis	6.86	8.37	11.32	5.25
Aeropedellus clavatus	5.13	3.02	6.23	1.85
Melanoplus femurrubrum	3.40	1.75	8.68	3.55
Melanoplus packardii	3.20	4.58	4.53	4.78
Melanoplus confusus	2.73	3.41	0.00	0.46
Aulocara elliotti	1.40	0.97	1.13	0.31
Melanoplus dawsonii	1.27	1.85	0.38	1.39
Metator pardalinus	0.80	1.46	1.70	1.24
Dissosteira carolina	0.33	0.10	0.76	0.15
Arphia pseudonietana	0.13	0.68	0.00	0.46
Arphia conspersa	0.13	0.29	0.76	0.77
Spharagemon collare	0.13	0.00	0.36	0.00
Boopedon nubilum	0.13	2.82	0.19	1.70
Trachyrhachys kiowa	0.07	4.48	0.19	4.78
Amphitornus coloradus	0.07	1.56	0.19	1.39
Chorthippus curtipennis	0.00	0.29	1.32	0.00
Encoptolophus costalis	0.00	0.00	0.76	0.15
Aeoloplides tenuipennis	0.00	0.97	0.38	1.70
Phlibostroma quadrimaculatum	0.00	13.05	0.00	11.57
Opeia obscura	0.00	5.75	0.00	3.40
Melanoplus gladstoni	0.00	4.77	0.00	0.15
Melanoplus keeleri	0.00	1.07	0.00	1.24
Hesperotettix viridis	0.00	0.97	0.00	0.15
Hadrotettix trifasciatus	0.00	0.68	0.00	0.00
Eritettix simplex	0.00	0.49	0.00	1.24
Hypochlora alba	0.00	0.10	0.00	0.00
Psoloessa delicatula	0.00	0.10	0.00	1.54
Mermiria bivittata	0.00	0.10	0.00	0.31
Aulocara femoratum	0.00	0.00	0.00	1.39

[a] 1,502 and 1,027 insects collected at the carbaryl–bran bait and control sites, respectively.
[b] 530 and 648 insects collected at the carbaryl–bran bait and control sites, respectively.

Table 41–Frequency of instars and adults of all grasshopper species combined on the pretreatment sampling dates at the six carbaryl–bran bait hot-spot treatment studies

Study	Instar/ stage	Frequency (%) 1st pretreatment date	2d pretreatment date
Tobacco Garden–Bran[a]	1st	1.38	1.78
	2d	3.91	0.68
	3d	10.99	4.50
	4th	17.99	12.65
	5th	28.67	30.90
	Adult	37.05	49.49
Hay Draw—1990[b]	1st	10.49	11.27
	2d	19.70	14.06
	3d	20.77	19.04
	4th	30.51	32.80
	5th	0.43	0.00
	Adult	18.09	22.83
Hay Draw—1991[c]	1st	6.75	—
	2d	19.09	—
	3d	27.56	—
	4th	30.14	—
	5th	0.80	—
	Adult	15.65	—
Cottonwood Creek[d]	1st	7.01	1.28
	2d	16.66	7.69
	3d	40.46	30.47
	4th	26.94	30.67
	5th	2.34	9.07
	Adult	6.59	20.81
Antelope Creek[e]	1st	3.15	7.44
	2d	13.71	22.20
	3d	47.01	20.79
	4th	30.90	18.38
	5th	3.46	19.45
	Adult	1.78	11.74

Table 41–Frequency of instars and adults of all grasshopper species combined on the pretreatment sampling dates at the six carbaryl-bran bait hot-spot treatment studies *(continued)*

Study	Instar/ stage	Frequency (%) 1st pretreatment date	2d pretreatment date
Cottonwood Creek II[f]	1st	14.23	—
	2d	25.35	—
	3d	41.37	—
	4th	15.33	—
	5th	0.23	—
	Adult	3.48	—
Schapers[g]	1st	0.06	—
	2d	2.09	—
	3d	24.23	—
	4th	33.20	—
	5th	37.87	—
	Adult	2.54	—

[a] First pretreatment date, 8 July 1990; second pretreatment date, 13 July 1990.
[b] First pretreatment date, 16 June 1990; second pretreatment date, 18 June 1990.
[c] Pretreatment date, 11 June 1991.
[d] First pretreatment date, 18 June 1990; second pretreatment date, 27 June 1990.
[e] First pretreatment date, 21 June 1990; second pretreatment date, 10 July 1990.
[f] Pretreatment date, 14 June 1991.
[g] Pretreatment date, 22 June 1991.

Table 42–Pretreatment densities and percentage of change in densities of grasshoppers, Tobacco Garden–Bait block, 1990–91

Population variable	Grasshopper taxon	Bran-bait[a]	Control[a]
Pretreatment density	All grasshoppers[b]	29.57 ± 3.609 (10) a	12.48 ± 2.561 (10) b
	Bran accepting	24.81 ± 3.438 (10) a	7.44 ± 2.444 (10) b
	Bran rejecting	1.71 ± 0.338 (10) a	2.27 ± 0.583 (10) a
	Bran vulnerable[b]	3.87 ± 0.841 (10) a	1.73 ± 0.546 (10) a
	M. infantilis	4.05 ± 1.160 (10) a	1.21 ± 0.377 (10) b
	C. pellucida	9.48 ± 2.178 (10) a	1.45 ± 1.358 (10) b
	M. sanguinipes	3.61 ± 0.686 (10) a	1.59 ± 0.733 (10) b
% change (1st pre- to 2-d posttreatment)	All grasshoppers[b]	–58.48 ± 7.992 (10)	–14.58 ± 9.479 (10)
	Bran accepting	–64.03 ± 7.415 (10)	–10.89 ± 9.721 (10)
	Bran vulnerable[b]	–23.78 ± 22.147 (8)	10.16 ± 43.903 (9)
	M. infantilis	–47.72 ± 10.558 (9)	–30.55 ± 31.219 (8)
	C. pellucida	–66.41 ± 14.197 (10)	57.41 ± 62.858 (6)
	M. sanguinipes	–23.23 ± 28.186 (10)	226.41 ± 139.576 (10)
% change (2nd pre- to 2-d posttreatment)	All grasshoppers[b]	–44.21 ± 9.225 (10)	37.80 ± 23.812 (10)
	Bran accepting	–60.18 ± 10.205 (10)	22.30 ± 23.808 (10)
	Bran vulnerable[b]	–5.86 ± 14.161 (7)	146.08 ± 97.979 (9)
	M. infantilis	–55.23 ± 19.118 (9)	–29.34 ± 20.800 (6)
	C. pellucida	–69.65 ± 15.897 (10)	–1.62 ± 28.526 (6)
	M. sanguinipes	–71.12 ± 17.171 (10)	49.44 ± 38.350 (10)
% change (after two applications)	All grasshoppers[b]	–75.89 ± 6.533 (10)	14.20 ± 19.613 (10)
	Bran accepting	–86.87 ± 3.731 (10)	9.97 ± 23.952 (10)
	Bran vulnerable[b]	–12.09 ± 32.630 (8)	71.02 ± 51.323 (9)
	M. infantilis	–71.86 ± 15.143 (9)	–15.12 ± 32.984 (8)
	C. pellucida	–94.33 ± 3.474 (10)	46.75 ± 74.534 (5)
	M. sanguinipes	–87.20 ± 5.294 (10)	638.49 ± 399.337 (10)
% change (1st pre-[c] to June 1991)	All grasshoppers[b]	17.93 ± 16.673 (10)	129.83 ± 78.613 (10)
	Bran accepting	3.09 ± 16.673 (10)	140.93 ± 84.196 (10)
	Bran vulnerable[b]	169.73± 114.211 (8)	362.82 ± 211.898 (9)
	M. infantilis	117.07 ± 95.711 (9)	194.80 ± 104.208 (8)
	C. pellucida	–62.48 ± 17.592 (10)	0.08 ± 33.518 (5)
	M. sanguinipes	232.03± 149.907 (10)	620.86 ± 401.797 (10)
% change (1st pre-[c] to July 1991)	All grasshoppers[b]	3.11 ± 9.522 (10)	130.96 ± 54.157 (10)
	Bran accepting	–26.70 ± 10.140 (10)	102.29 ± 63.638 (10)
	Bran vulnerable[b]	343.62 ± 100.724 (8)	778.86 ± 342.589 (9)
	M. infantilis	22.69 ± 52.707 (9)	107.38 ± 84.193 (8)
	C. pellucida	–84.34 ± 4.566 (10)	35.16 ± 68.180 (5)
	M. sanguinipes	395.06 ± 284.521 (10)	871.95 ± 631.990 (10)

[a]Values are means ± 1 SEM with sample sizes in parentheses. Means followed by the same letter within rows are not significantly different (Kruskal–Wallis test, $P > 0.05$).

[b] Does not include late-hatching species.

[c] Change in grasshopper densities between the first pretreatment date and average June and July 1991 densities.

Table 43–Grasshopper species composition at the Hay Draw block on the pretreatment sample dates, 16 and 18 June 1990 and 11 June 1991

	% of total					
	16 June 1990[a]		18 June 1990[b]		11 June 1991[c]	
Species	Bran-bait	Control	Bran-bait	Control	Bran-bait	Control
Aeropedellus clavatus	47.00	33.83	53.44	37.20	40.14	20.78
Camnula pellucida	42.61	5.47	35.29	5.31	46.61	8.80
Melanoplus infantilis	3.75	18.41	2.39	16.43	1.90	20.42
Melanoplus sanguinipes	2.25	1.49	3.49	6.76	2.21	8.80
Melanoplus bivittatus	1.93	15.92	1.00	5.31	4.34	10.56
Aulocara elliotti	1.18	1.00	1.10	0.00	0.84	1.76
Amphitornus coloradus	0.64	5.47	1.60	9.18	1.14	2.82
Melanoplus confusus	0.32	8.46	0.50	7.25	1.37	11.27
Ageneotettix deorum	0.21	1.00	0.00	3.38	0.08	3.52
Metator pardalinus	0.11	0.50	0.00	1.45	0.00	0.00
Arphia conspersa	0.00	0.00	0.90	0.00	0.08	1.06
Eritettix simplex	0.00	2.49	0.20	1.45	0.08	0.35
Trachyrhachys kiowa	0.00	0.10	0.10	0.48	0.84	1.06
Phlibostroma quadrimaculatum	0.00	1.99	0.00	2.42	0.00	3.17
Melanoplus packardii	0.00	1.49	0.00	1.93	0.23	2.82
Opeia obscura	0.00	1.00	0.00	1.45	0.00	0.00
Hadrotettix trifasciatus	0.00	0.50	0.00	0.00	0.00	0.35
Melanoplus femurrubrum	0.00	0.00	0.00	0.00	0.08	0.70
Boopedon nubilum	0.00	0.00	0.00	0.00	0.08	1.41
Xanthippus corallipes	0.00	0.00	0.00	0.00	0.00	0.35

[a] 934 and 201 insects collected at the carbaryl–bran bait and control sites, respectively, on the first pretreatment date.
[b] 1,003 and 207 insects collected at the carbaryl–bran bait and control sites, respectively, on the second pretreatment date.
[c] 1,313 and 316 insects collected at the carbaryl–bran bait and control sites, respectively, on the third pretreatment date.

Table 44–Pretreatment densities and percentage of change in densities of grasshoppers, Hay Draw block, 1990–91

Population variable	Grasshopper variable	Bran-bait[a]	Control[a]
Pretreatment density	All grasshoppers[b]	51.25 ± 10.897 (3)a	8.75 ± 3.100 (3)b
	Bran accepting	25.05 ± 9.326 (3)a	4.75 ± 1.868 (3)b
	Bran rejecting	26.20 ± 2.771 (3)a	3.87 ± 1.548 (3)b
	Bran vulnerable[b]	0.00 ± 0.000 (3)a	0.12 ± 0.122 (3)a
	A. clavatus	25.74 ± 2.493 (3)a	3.00 ± 1.568 (3)b
	C. pellucida	19.62 ± 9.365 (3)a	0.46 ± 0.374 (3)b
% change (1st pre- to 2-d posttreatment)	All grasshoppers[b]	–21.42 ± 17.320 (3)	16.00 ± 21.030 (3)
	Bran accepting	–24.06 ± 19.915 (3)	–20.31 ± 6.216 (3)
	Bran rejecting	–18.60 ± 14.971 (3)	50.42 ± 40.202 (3)
	A. clavatus	–19.50 ± 14.711 (3)	17.46 ± 54.215 (2)
	C. pellucida	–15.00 ± 30.127 (3)	–61.49 ± 38.510 (2)
% change (2nd pre- to 2-d posttreatment)	All grasshoppers[b]	–44.23 ± 3.962 (3)	–11.28 ± 11.940 (3)
	Bran accepting	–55.94 ± 4.566 (3)	34.39 ± 20.219 (3)
	Bran rejecting	–33.69 ± 8.488 (3)	–21.89 ± 26.160 (3)
	A. clavatus	–38.11 ± 9.716 (3)	–49.98 ± 33.883 (3)
	C. pellucida	–68.59 ± 5.813 (3)	–83.57 ± — (1)
% change (after two applications)	All grasshoppers[b]	–57.27 ± 7.887 (3)	5.25 ± 29.768 (3)
	Bran accepting	–68.28 ± 5.308 (3)	7.24 ± 18.737 (3)
	Bran rejecting	47.79 ± 8.013 (3)	27.04 ± 68.349 (3)
	A. clavatus	51.64 ± 9.312 (3)	–59.62 ± 12.680 (2)
	C. pellucida	75.42 ± 6.752 (3)	–93.67 ± 6.328 (2)
% change (pre- to[c] July 1990)	All grasshoppers[b]	–50.97 ± 13.221 (3)	93.55 ± 87.068 (3)
	Bran accepting	39.93 ± 33.765 (3)	66.13 ± 71.243 (3)
	Bran rejecting	–57.23 ± 4.967 (3)	112.79 ± 133.046 (3)
	A. clavatus	–75.89 ± 4.142 (3)	–52.47 ± 25.209 (2)
	C. pellucida	–52.32 ± 34.904 (3)	71.46 ± 148.435 (2)
% change (1st pre- to 11 June 1991)	All grasshoppers[b]	9.60 ± 57.058 (3)	30.16 ± 48.726 (3)
	Bran accepting	50.07 ± 106.636 (3)	21.42 ± 39.055 (3)
	Bran rejecting	–12.19 ± 24.180 (3)	64.74 ± 91.766 (3)
	A. clavatus	–15.98 ± 26.202 (3)	–27.43 ± 43.134 (2)
	C. pellucida	85.58 ± 157.976 (3)	158.25 ± 115.371 (2)
% change (3rd pre- to 2-d posttreatment)	All grasshoppers[b]	–34.32 ± 7.335 (3)	–4.87 ± 8.956 (3)
	Bran accepting	–34.87 ± 8.030 (3)	8.89 ± 19.119 (3)
	Bran rejecting	11.58 ± 5.136 (3)	–30.20 ± 0.934 (3)
	A. clavatus	16.20 ± 6.424 (3)	–4.17 ± 10.339 (3)
	C. pellucida	58.36 ± 15.630 (3)	–74.02 ± 25.981 (2)

Table 44–Pretreatment densities and percentage of change in densities of grasshoppers, Hay Draw block, 1990–91 ***(continued)***

Population variable	Grasshopper variable	Bran-bait[a]	Control[a]
% change (3rd pre- to[d] July 1991)	All grasshoppers[b]	–42.77 ± 12.679 (3)	56.99 ± 31.868 (3)
	Bran accepting	47.31 ± 9.221 (3)	39.89 ± 30.807 (3)
	Bran rejecting	43.95 ± 15.020 (3)	33.23 ± 27.984 (3)
	A. clavatus	–68.55 ± 6.000 (3)	–24.76 ± 6.989 (3)
	C. pellucida	61.45 ± 7.754 (3)	–49.13 ± 34.753 (2)

[a] Values are means ± 1 SEM with sample sizes are in parentheses. Means followed by the same letter within rows are not significantly different (Kruskal–Wallis test, $P > 0.05$).
[b] Does not include late-hatching species.
[c] Change in grasshopper densities between the first pretreatment and average July 1990 densities.
[d] Change in grasshopper densities between the third pretreatment and average July 1991 densities.

Table 45–Grasshopper species composition at the Cottonwood Creek block on the pretreatment sample dates, 18 and 27 June 1990

	% of total			
	18 June 1990[a]		27 June 1990[b]	
Species	Bran-bait	Control	Bran-bait	Control
Camnula pellucida	19.87	0.54	26.87	0.47
Aeropedellus clavatus	19.03	6.84	28.40	6.10
Ageneotettix deorum	15.08	27.16	3.40	26.53
Melanoplus infantilis	14.47	3.42	12.08	8.45
Aulocara elliotti	11.85	8.63	3.91	7.04
Melanoplus confusus	5.18	4.50	1.70	5.63
Melanoplus sanguinipes	4.40	8.09	10.03	7.51
Amphitornus coloradus	4.01	28.60	4.59	19.01
Melanoplus bivittatus	3.40	0.54	1.87	1.17
Trachyrhachys kiowa	0.84	1.80	3.40	5.87
Metator pardalinus	0.67	1.26	0.00	0.00
Melanoplus packardii	0.45	3.96	2.38	4.70
Phlibostroma quadrimaculatum	0.33	1.26	0.17	2.35
Hesperotettix viridis	0.28	0.36	0.51	0.70
Melanoplus dawsonii	0.06	0.00	0.00	0.24
Eritettix simplex	0.06	0.90	0.17	0.94
Psoloessa delicatula	0.06	0.00	0.00	1.17
Hypochlora alba	0.00	1.26	0.51	0.24
Acrolophitus hirtipes	0.00	0.36	0.00	0.00
Melanoplus keeleri	0.00	0.36	0.00	1.41
Pardalophora haldemanii	0.00	0.18	0.00	0.00
Arphia conspersa	0.00	0.00	0.00	0.24
Boopedon nubilum	0.00	0.00	0.00	0.24

[a] 1,797 and 556 insects collected at the carbaryl–bran bait and control sites, respectively, on the first pretreatment date.
[b] 588 and 426 insects collected at the carbaryl–bran bait and control sites, respectively, on the second pretreatment date.

Table 46–Pretreatment densities and percentage of change in densities of grasshoppers, Cottonwood Creek block, 1990–91

Population variable	Grasshopper variable	Bran-bait[a]	Control[a]
Pretreatment density	All grasshoppers[b]	23.94 ± 5.668 (6)a	6.20 ± 1.263 (6)b
	Bran accepting	16.62 ± 3.997 (6)a	3.68 ± 0.692 (6)b
	Bran rejecting	7.32 ± 2.747 (6)a	2.37 ± 0.596 (6)a
	Bran vulnerable[b]	0.00 ± 0.000 (6)a	0.00 ± 0.000 (6)a
	C. pellucida	5.85 ± 3.960 (6)a	0.03 ± 0.017 (6)b
	A. clavatus	5.89 ± 2.939 (6)a	0.59 ± 0.200 (6)a
	A. deorum	2.70 ± 1.118 (6)a	1.53 ± 0.422 (6)a
	M. infantilis	2.48 ± 0.989 (6)a	0.45 ± 0.247 (6)b
	A. elliotti	2.74 ± 0.766 (6)a	0.52 ± 0.203 (6)b
% change (1st pre- to 2-d postreatment	All grasshoppers[b]	–69.04 ± 4.141 (6)	16.10 ± 25.678 (6)
	Bran accepting	–71.90 ± 5.051 (6)	32.25 ± 31.823 (6)
	Bran rejecting	–36.42 ± 19.250 (6)	–11.67 ± 20.637 (6)
	C. pellucida	–81.61 ± 11.022 (6)	–38.00 ± 62.002 (2)
	A. clavatus	31.86 ± 71.821 (6)	4.25 ± 45.485 (5)
	A. deorum	–89.40 ± 3.465 (5)	21.96 ± 30.436 (5)
	M. infantilis	–67.94 ± 11.147 (5)	49.27 ± 57.638 (4)
	A. elliotti	–88.26 ± 5.294 (5)	–18.90 ± 25.016 (4)
% change (2nd pre- to 2-d posttreatment)	All grasshoppers[b]	–22.61 ± 7.370 (6)	–20.81 ± 7.553 (6)
	Bran accepting	–32.16 ± 4.691 (6)	–11.85 ± 11.124 (6)
	Bran rejecting	–11.31 ± 11.603 (6)	–26.12 ± 12.442 (6)
	C. pellucida	–50.53 ± 6.076 (3)	–15.47 ± 84.531 (2)
	A. clavatus	–21.02 ± 16.083 (6)	29.80 ± 46.119 (4)
	A. deorum	65.33 ± 54.647 (5)	–19.64 ± 8.811 (6)
	M. infantilis	–56.07 ± 11.336 (4)	27.47 ± 35.043 (6)
	A. elliotti	–53.80 ± 13.808 (4)	–11.24 ± 41.902 (4)
% change (after two applications)	All grasshoppers[b]	–76.82 ± 2.488 (6)	–6.51 ± 24.625 (6)
	Bran accepting	–81.06 ± 3.497 (6)	24.81 ± 40.107 (6)
	Bran rejecting	–43.33 ± 17.898 (6)	–43.04 ± 10.267 (6)
	C. pellucida	–76.85 ± 12.786 (6)	4.82 ± 104.822 (2)
	A. clavatus	–23.40 ± 28.056 (6)	–3.15 ± 29.387 (5)
	A. deorum	–81.57 ± 11.880 (5)	5.07 ± 31.807 (5)
	M. infantilis	–86.75 ± 4.800 (5)	36.02 ± 68.762 (4)
	A. elliotti	–95.15 ± 1.022 (5)	–31.59 ± 36.287 (4)

Table 46–Pretreatment densities and percentage of change in densities of grasshoppers, Cottonwood Creek block, 1990–91 *(continued)*

Population variable	Grasshopper variable	Bran-bait[a]	Control[a]
% change (1st pre- to[c] July 1990)	All grasshoppers[b]	−66.54 ± 4.523 (6)	38.09 ± 30.707 (6)
	Bran accepting	−76.26 ± 7.637 (6)	17.17 ± 29.256 (6)
	Bran rejecting	−26.16 ± 19.171 (6)	28.74 ± 34.741 (6)
	C. pellucida	−89.90 ± 5.828 (6)	−49.10 ± 50.901 (2)
	A. clavatus	−53.05 ± 9.762 (6)	−40.44 ± 22.621 (5)
	A. deorum	−77.30 ± 13.278 (5)	28.36 ± 33.586 (5)
	M. infantilis	−71.88 ± 6.299 (5)	22.46 ± 48.488 (4)
	A. elliotti	−90.87 ± 4.123 (5)	−42.01 ± 12.386 (4)
% change (1st pre- to[c] June 1991)	All grasshoppers[b]	−70.78 ± 4.254 (6)	7.28 ± 21.512 (6)
	Bran accepting	−70.90 ± 7.095 (6)	−1.32 ± 19.590 (6)
	Bran rejecting	−41.24 ± 19.698 (6)	26.03 ± 41.733 (6)
	C. pellucida	−88.01 ± 3.851 (6)	−33.54 ± 66.457 (2)
	A. clavatus	16.23 ± 58.158 (6)	56.25 ± 77.895 (5)
	A. deorum	−84.45 ± 10.839 (5)	−29.66 ± 23.871 (5)
	M. infantilis	−51.78 ± 15.413 (5)	26.57 ± 48.787 (4)
	A. elliotti	−81.91 ± 4.854 (5)	−17.21 ± 32.415 (4)
% change (1st pre- to[c] July 1991)	All grasshoppers[b]	−49.40 ± 3.264 (6)	19.34 ± 21.480 (6)
	Bran accepting	−46.91 ± 9.492 (6)	4.11 ± 22.800 (6)
	Bran rejecting	−26.80 ± 23.541 (6)	4.54 ± 18.872 (6)
	C. pellucida	−86.89 ± 5.865 (6)	−100.00 ± 0.000 (2)
	A. clavatus	−16.20 ± 6.424 (3)	−51.89 ± 14.342 (5)
	A. deorum	−72.14 ± 12.671 (5)	5.40 ± 22.852 (5)
	M. infantilis	−79.52 ± 9.753 (5)	−48.56 ± 24.099 (4)
	A. elliotti	−85.68 ± 9.890 (5)	−54.91 ± 17.134 (4)

[a] Values are means ± 1 SEM with sample sizes in parentheses. Means followed by the same letter within rows are not significantly different (Kruskal–Wallis test, $P > 0.05$).

[b] Does not include late-hatching species.

[c] Change in grasshopper densities between the first pretreatment and average July 1990, June 1991, and July 1991 densities.

Table 47–Grasshopper species composition at the Antelope Creek block on the pretreatment sample dates, 21 June and 10 July 1990

	% of total			
	21 June 1990[a]		10 July 1990[b]	
Species	Bran-bait	Control	Bran-bait	Control
Melanoplus infantilis	83.13	65.71	51.52	44.47
Cammula pellucida	8.63	1.31	0.97	0.26
Melanoplus sanguinipes	2.90	3.14	2.36	9.75
Aeropedellus clavatus	2.51	5.76	5.13	0.52
Ageneotettix deorum	2.48	17.80	1.39	8.58
Aulocara elliotti	0.04	2.88	0.00	0.00
Amphitornus coloradus	0.07	0.26	0.14	0.26
Encoptolophus costalis	0.04	0.00	18.84	14.30
Eritettix simplex	0.04	0.26	0.00	0.00
Trachyrhachys kiowa	0.18	0.79	1.52	3.38
Phoetaliotes nebrascensis	0.00	0.00	12.74	2.60
Hypochlora alba	0.00	0.00	1.80	0.00
Phlibostroma quadrimaculatum	0.00	0.00	0.97	2.21
Opeia obscura	0.00	0.00	0.83	1.82
Hesperotettix viridis	0.00	0.00	0.55	0.13
Arphia pseudonietana	0.00	0.00	0.42	0.52
Metator pardalinus	0.00	0.00	0.42	0.00
Melanoplus femurrubrum	0.00	0.26	0.28	0.52
Chorthippus curtipennis	0.00	0.00	0.14	0.00
Arphia conspersa	0.00	0.26	0.00	0.00
Melanoplus packardii	0.00	0.52	0.00	0.65
Psoloessa delicatula	0.00	1.05	0.00	0.00
Unknown Oedipodinae	0.00	0.00	0.00	0.13
Melanoplus dawsonii	0.00	0.00	0.00	2.60
Melanoplus gladstoni	0.00	0.00	0.00	6.50
Orphulella speciosa	0.00	0.00	0.00	0.78

[a] 2,828 and 382 insects collected at the carbaryl–bran bait and control sites, respectively, on the first pretreatment date.
[b] 722 and 769 insects collected at the carbaryl–bran bait and control sites, respectively, on the second pretreatment date.

Table 48–Pretreatment densities and percentage of change in densities of grasshoppers, Antelope Creek block, 1990–91

Populations variable	Grasshopper taxon	Bran-bait[a]	Control[a]
Pretreatment density	All grasshoppers[b]	50.88 ± 12.565 (5)a	5.67 ± 1.713 (5)b
	Bran accepting	49.13 ± 12.419 (5)a	5.17 ± 1.722 (5)b
	Bran rejecting	1.73 ± 0.469 (5)a	0.46 ± 0.101 (5)b
	Bran vulnerable[b]	0.00 ± 0.000 (5)a	0.04 ± 0.036 (5)a
	M. infantilis	40.24 ± 11.916 (5)a	3.68 ± 1.316 (5)b
% change (1st pre- to 2-d posttreatment)	All grasshoppers[b]	–57.18 ± 6.504 (5)	15.87 ± 11.035 (5)
	Bran accepting	–60.24 ± 5.790 (5)	23.62 ± 12.236 (5)
	M. infantilis	–55.83 ± 7.193 (5)	62.42 ± 26.293 (5)
% change (2nd pre- to 2-d posttreatment)	All grasshoppers[b]	–42.61 ± 7.833 (5)	–6.67 ± 23.818 (5)
	Bran accepting	–28.52 ± 13.145 (5)	36.48 ± 55.220 (5)
	M. infantilis	–23.08 ± 17.091 (5)	147.46 ± 84.803 (5)
% change (after two applications)	All grasshoppers[b]	–81.38 ± 4.821 (5)	102.40 ± 75.205 (5)
	Bran accepting	–87.04 ± 3.126 (5)	85.59 ± 69.091 (5)
	M. infantilis	–84.08 ± 3.927 (5)	545.70 ± 478.042 (5)
% change (1st pre- to[c] July 1990	All grasshoppers[b]	–83.32 ± 4.060 (5)	102.09 ± 60.212 (5)
	Bran accepting	–89.21 ± 2.228 (5)	78.49 ± 45.317 (5)
	M. infantilis	–86.80 ± 3.356 (5)	419.65 ± 344.563 (5)
% change (1st pre- to[c] June 1991)	All grasshoppers[b]	–60.31 ± 6.299 (5)	95.76 ± 60.010 (5)
	Bran accepting	–62.99 ± 6.442 (5)	74.63 ± 54.524 (5)
	M. infantilis	–60.10 ± 11.434 (5)	165.82 ± 121.453 (5)

[a] Values are means ± 1 SEM with sample sizes in parentheses. Means followed by the same letter within rows are not significantly different (Kruskal–Wallis test, $P > 0.05$).

[b] Does not include late-hatching species.

[c] Change in grasshopper densities between the first pretreatment and average July 1990 and June 1991 densities.

Table 49–Grasshopper species composition at the Cottonwood Creek II block on the pretreatment sample date, 14 June 1991

Species	% of total[a]	
	Bran-bait	Control
Melanoplus infantilis	37.06	29.28
Ageneotettix deorum	23.52	21.10
Aulocara elliotti	8.48	2.56
Aeropedellus clavatus	4.99	7.03
Camnula pellucida	4.99	11.36
Trachyrhachys kiowa	4.42	1.28
Melanoplus sanguinipes	4.13	3.84
Melanoplus packardii	3.21	4.73
Amphitornus coloradus	2.21	1.92
Metator pardalinus	1.57	0.00
Hypochlora alba	1.43	0.00
Phlibostroma quadrimaculatum	1.21	1.92
Hesperotettix viridis	0.71	1.54
Melanoplus confusus	0.64	9.59
Orphulella speciosa	0.57	0.00
Psoloessa delicatula	0.36	0.13
Unknown Oedipodinae	0.14	0.00
Eritettix simplex	0.14	0.38
Xanthippus corallipes	0.07	0.00
Opeia obscura	0.07	0.26
Arphia pseudonietana	0.07	0.00
Melanoplus femurrubrum	0.00	1.92
Melanoplus bivittatus	0.00	0.77
Encoptolophus costalis	0.00	0.13
Mermiria bivittata	0.00	0.13
Melanoplus dawsonii	0.00	0.13

[a] 1,403 and 782 insects collected in the carbaryl–bran bait and control sites, respectively.

Table 50–Pretreatment densities and percentage of change in densities of grasshoppers, Cottonwood Creek II block, 1991–92

Population variable	Grasshopper taxon	Bran-bait[a]	Control[a]
Pretreatment density	All grasshoppers[b]	13.42 ± 2.626 (5)a	7.96 ± 2.230 (5)b
	Bran accepting	11.24 ± 2.278 (5)a	6.74 ± 2.038 (5)a
	Bran rejecting	1.96 ± 0.604 (5)a	1.04 ± 0.113 (5)a
	Bran vulnerable[b]	0.01 ± 0.006 (5)a	0.17 ± 0.146 (5)a
	M. infantilis	5.31 ± 1.328 (5)a	2.47 ± 0.971 (5)a
	A. deorum	2.98 ± 0.772 (5)a	1.43 ± 0.423 (5)b
% change (pre- to 3-d posttreatment)	All grasshoppers[b]	–52.32 ± 7.576 (5)	–19.17 ± 22.581 (5)
	Bran accepting	–59.56 ± 3.306 (5)	–20.72 ± 25.158 (5)
	Bran rejecting	–16.52 ± 23.572 (5)	23.01 ± 17.924 (5)
	M. infantilis	–66.28 ± 5.152 (5)	20.90 ± 70.346 (5)
	A. deorum	–54.45 ± 5.407 (5)	–54.94 ± 21.356 (5)
% change (pre- to[c] July 1991)	All grasshoppers[b]	–59.28 ± 7.147 (5)	–23.13 ± 9.244 (5)
	Bran accepting	–66.90 ± 4.592 (5)	–37.60 ± 7.795 (5)
	Bran rejecting	–27.03 ± 20.722 (5)	6.32 ± 18.994 (5)
	M. infantilis	–76.49 ± 3.631 (5)	–78.34 ± 4.659 (5)
	A. deorum	–66.89 ± 7.919 (5)	–4.22 ± 17.433 (5)
% change (pre- to[c] June 1992)	All grasshoppers[b]	9.09 ± 8.147 (5)	–14.64 ± 17.387 (5)
	Bran accepting	21.14 ± 9.239 (5)	–10.02 ± 15.659 (5)
	Bran rejecting	–34.15 ± 13.550 (5)	–32.96 ± 26.181 (5)
	M. infantilis	–53.90 ± 19.061 (5)	–79.86 ± 7.036 (5)
	A. deorum	–64.61 ± 8.175 (5)	–47.13 ± 17.436 (5)

[a] Values are means ± 1 SEM with sample sizes in parentheses. Means followed by the same letter within rows are not significantly different (Kruskal–Wallis test, $P > 0.05$).
[b] Does not include late-hatching species.
[c] Change in grasshopper densities between the first pretreatment and average July 1991 and June 1992 densities.

Table 51–Grasshopper species composition at the Schapers block on the pretreatment sample date, 22 June 1991

Species	% of total[a]	
	Bran-bait	Control
Aulocara elliotti	53.81	2.72
Camnula pellucida	28.69	12.42
Melanoplus infantilis	6.67	12.76
Melanoplus sanguinipes	5.24	37.25
Ageneotettix deorum	1.48	6.63
Phlibostroma quadrimaculatum	0.99	5.27
Melanoplus packardii	0.71	1.87
Melanoplus bivittatus	0.64	2.72
Amphitornus coloradus	0.56	1.87
Aeropedellus clavatus	0.48	6.12
Trachyrhachys kiowa	0.52	2.72
Melanoplus confusus	0.12	5.95
Eritettix simplex	0.12	0.17
Hypochlora alba	0.00	0.85
Arphia pseudonietana	0.00	0.17
Arphia conspersa	0.00	0.34
Mermiria bivittata	0.00	0.17

[a] 2,520 and 588 insects collected in the carbaryl–bran bait and control sites, respectively.

Table 52–Pretreatment densities and percentage of change in densities of grasshoppers, Schapers block, 1991–92

Population variable	Grasshopper variable	Bran-bait[a]	Control[a]
Pretreatment density	All grasshoppers[b]	43.60 ± 8.376 (5)a	8.25 ± 2. 160 (5)b
	Bran accepting	42.03 ± 9.266 (5)a	6.70 ± 1.568 (5)b
	Bran rejecting	1.58 ± 1.185 (5)a	1.44 ± 0.773 (5)a
	Bran vulnerable[b]	0.00 ± 0.000 (5)a	0.00 ± 0.000 (5)a
	A. elliotti	22.06 ± 10.090 (5)a	0.22 ± 0.065 (5)b
	C. pellucida	12.77 ± 10.307 (5)a	0.83 ± 0.506 (5)a
% change (pre- to 2-d posttreatment	All grasshoppers[b]	–68.53 ± 7.531 (5)	–32.94 ± 9.588 (5)
	Bran accepting	–71.32 ± 7.806 (5)	–36.47 ± 12.625 (5)
	A. elliotti	–76.31 ± 4.513 (5)	–59.31 ± 23.529 (4)
	C. pellucida	–53.27 ± 22.668 (3)	–40.36 ± 32.913 (3)
% change (pre- to[c] July 1991	All grasshoppers[b]	–76.33 ± 7.416 (5)	–15.37 ± 19.074 (5)
	Bran accepting	–81.69 ± 5.480 (5)	–33.34 ± 23.354 (5)
	A. elliotti	–78.84 ± 9.185 (5)	20.50 ± 93.443 (4)
	C. pellucida	–94.66 ± 2.326 (3)	58.68 ± 125.615 (3)
% change (pre- to 18 June 1992)	All grasshoppers[b]	–69.66 ± 5.699 (5)	–18.68 ± 12.041 (5)
	Bran accepting	–69.29 ± 5.295 (5)	–27.44 ± 11.930 (5)
	A. elliotti	–90.32 ± 5.213 (5)	–43.24 ± 23.902 (4)
	C. pellucida	–87.94 ± 9.193 (3)	70.89 ± 157.106 (3)
% change (pre- to[c] July 1992)	All grasshoppers[b]	–56.91 ± 8.659 (5)	4.94 ± 14.725 (5)
	Bran accepting	–57.74 ± 10.634 (5)	–12.67 ± 15.011 (5)
	A. elliotti	–87.92 ± 5.915 (5)	–70.28 ± 14.881 (4)
	C. pellucida	–20.61 ± 72.558 (3)	–13.57 ± 69.703 (3)

[a] Values are means ± 1 SEM with sample sizes in parentheses. Means followed by the same letter within rows are not significantly different (Kruskal–Wallis test, $P > 0.05$).

[b] Does not include late-hatching species.

[c] Change in grasshopper densities between the first pretreatment and average July 1991 and July 1992 densities.

Table 53–Grasshopper species composition at the Mead block on the pretreatment sample date, 9 July 1992

	% of total[a]		
	Swath width (m)		
Species	13.7	27.4	Control
Melanoplus sanguinipes	48.98	17.74	34.33
Melanoplus infantilis	10.51	42.07	20.56
Melanoplus packardii	13.47	6.99	6.05
Ageneotettix deorum	4.03	14.39	9.86
Melanoplus gladstoni	4.68	0.76	0.47
Melanoplus femurrubrum	4.49	0.20	2.70
Phlibostroma quadrimaculatum	2.92	1.17	5.40
Aulocara elliotti	0.46	3.29	1.21
Camnula pellucida	0.37	3.40	0.37
Aeropedellus clavatus	1.90	1.37	0.65
Hypochlora alba	1.71	1.12	1.02
Trachyrhachys kiowa	0.51	2.28	5.12
Melanoplus confusus	0.97	1.06	0.93
Metator pardalinus	0.83	1.12	1.95
Amphitornus coloradus	0.65	0.30	0.93
Phoetaliotes nebrascensis	0.79	0.00	1.58
Melanoplus dawsonii	0.65	0.00	1.30
Melanoplus keeleri	0.37	0.25	0.28
Opeia obscura	0.28	0.36	2.14
Hesperotettix viridis	0.19	0.30	0.56
Melanoplus bivittatus	0.42	0.05	0.47
Spharagemon collare	0.14	0.36	0.09
Orphulella speciosa	0.42	0.00	0.19
Arphia conspersa	0.00	0.30	0.28
Arphia pseudonietana	0.05	0.15	0.00
Eritettix simplex	0.05	0.05	0.00
Mermiria bivittata	0.05	0.05	0.28
Aeoloplides turnbulli	0.05	0.00	0.00
Chorthippus curtipennis	0.05	0.00	0.09
Hadrotettix trifasciatus	0.00	0.05	0.19
Spharagemon equale	0.00	0.05	0.00
Xanthippus corallipes	0.05	0.00	0.00
Encoptolophus costalis	0.00	0.00	0.93
Pardalophora haldemanii	0.00	0.00	0.09

[a] 2,160, 1,972, and 1,075 insects collected in the bran–13.7-m, bran–27.4-m, and control sites, respectively.

Table 54–Frequency of instars and adults of all grasshopper species combined on the pretreatment sampling date at the four extended swath width carbaryl–bran bait studies

Study	Instar/Stage	Frequency (%)
Mead[a]	1st	2.63
	2d	6.84
	3d	18.42
	4th	32.17
	5th	32.40
	Adult	7.55
Crighton[b]	1st	4.61
	2d	4.93
	3d	16.82
	4th	28.73
	5th	32.17
	Adult	7.55
Wolf Coulee[c]	1st	8.45
	2d	21.51
	3d	40.16
	4th	18.70
	5th	9.16
	Adult	2.02
Corral Creek[d]	1st	4.95
	2d	19.28
	3d	37.88
	4th	23.53
	5th	11.59
	Adult	2.76

[a] Pretreatment date, 9 July 1992.
[b] Pretreatment dete, 4 July 1992.
[c] Pretreatment date, 17 July 1993.
[d] Pretreatment date, 18 July 1993.

Table 55–Pretreatment densities and percentage of change in densities of grasshoppers, Mead block, 1992

Population variable	Grasshopper taxon	Bran-bait (13.7-m)[a]	Bran-bait (27.4-m)[a]	Control[a]
Pretreatment density	All grasshoppers[b]	18.75 ± 5.548 (10)a	11.54 ± 1.868 (10)a	9.98 ± 1.867 (10)a
	Bran accepting	14.92 ± 4.768 (10)a	10.22 ± 1.713 (10)a	7.33 ± 1.452 (10)a
	Bran rejecting	1.37 ± 0.675 (10)a	0.94 ± 0.232 (10)a	1.41 ± 0.785 (10)a
	Bran vulnerable[b]	1.15 ± 0.736 (10)a	0.07 ± 0.041 (10)a	0.75 ± 0.218 (10)a
	M. sanguinipes	9.06 ± 3.270 (10)a	2.54 ± 0.659 (10)a	3.52 ± 1.066 (10)a
	M. infantilis	1.93 ± 0.529 (10)a	4.17 ± 0.824 (10)a	1.68 ± 0.467 (10)a
	M. packardii	2.61 ± 1.182 (10)a	0.76 ± 0.130 (10)a	0.67 ± 0.225 (10)b
	A. deorum	0.75 ± 0.196 (10)a	1.69 ± 0.374 (10)a	0.84 ± 0.957 (10)a
% change (pre- to 3-d post-treatment)	All grasshoppers[b]	–51.69 ± 7.763 (10)	–39.96 ± 10.007 (10)	–21.12 ± 12.261 (10)
	Bran accepting	–54.38 ± 7.049 (10)	–45.14 ± 10.844 (10)	–34.33 ± 9.742 (10)
	M. sanguinipes	–72.15 ± 9.876 (10)	208.02 ± 231.218 (10)	–16.00 ± 19.713 (10)
	M. infantilis	81.80 ± 135.235 (9)	–57.55 ± 7.932 (10)	–19.53 ± 27.950 (9)
	M. packardii	–43.43 ± 11.440 (10)	–64.02 ± 7.763 (9)	–26.95 ± 19.855 (8)
% change[c] (pre- to July 1992)	All grasshoppers[b]	–45.96 ± 7.497 (10)	–29.87 ± 10.071 (10)	–16.95 ± 12.588 (10)
	Bran accepting	–45.16 ± 7.957 (10)	–38.85 ± 10.675 (10)	–27.48 ± 9.557 (10)
	M. sanguinipes	–56.15 ± 6.617 (10)	99.82 ± 121.934 (10)	–17.96 ± 11.448 (10)
	M. infantilis	25.86 ± 64.522 (9)	–49.29 ± 5.187 (10)	8.69 ± 26.479 (9)
	M. packardii	–32.58 ± 11.578 (10)	–54.01 ± 7.408 (9)	–14.89 ± 18.279 (8)

[a] Values are means ± 1 SEM with sample sizes in parentheses. Means followed by the same letter within rows are not significantly different (Kruskal–Wallis test, $P > 0.05$).

[b] Does not include late-hatching species.

[c] Change in grasshopper densities between the pretreatment and average July 1992 densities.

Table 56–Grasshopper species composition at the Crighton block on the pretreatment sample date, 4 July 1992

Species	% of total[a]		
	swath width (m)		
	13.7	27.4	Control
Melanoplus sanguinipes	14.64	25.06	22.20
Phlibostroma quadrimaculatum	23.62	8.45	13.90
Camnula pellucida	5.44	23.06	5.60
Melanoplus infantilis	15.32	5.47	16.80
Aulocara elliotti	14.46	1.13	1.16
Aeropedellus clavatus	1.59	10.53	1.35
Trachyrhachys kiowa	5.44	5.62	9.85
Melanoplus gladstoni	0.18	7.17	1.74
Ageneotettix deorum	7.53	0.64	10.62
Melanoplus bivittatus	2.13	3.43	1.93
Melanoplus packardii	2.00	2.83	6.76
Amphitornus coloradus	2.77	0.72	2.90
Opeia obscura	0.32	1.36	1.74
Metator pardalinus	0.82	0.72	0.58
Aulocara femoratum	1.36	0.11	0.19
Melanoplus femurrubrum	0.32	0.91	0.19
Phoetaliotes nebrascensis	0.54	0.64	0.19
Encoptolophus costalis	0.00	0.72	0.00
Melanoplus confusus	0.59	0.19	1.16
Hesperotettix viridis	0.45	0.19	0.19
Melanoplus dawsonii	0.00	0.30	0.00
Arphia pseudonietana	0.00	0.23	0.00
Boopedon nubilum	0.14	0.11	0.19
Eritettix simplex	0.09	0.11	0.00
Chorthippus curtipennis	0.14	0.00	0.00
Hadrotettix trifasciatus	0.00	0.08	0.00
Hypochlora alba	0.00	0.08	0.00
Acrolophitus hirtipes	0.00	0.04	0.00
Aeoloplides turnbulli	0.05	0.00	0.00
Arphia conspersa	0.00	0.04	0.00
Dactylotum bicolor	0.00	0.04	0.00
Chorthippus viridifasciatus	0.00	0.04	0.00
Mermiria bivittata	0.05	0.00	0.58
Psoloessa delicatula	0.05	0.00	0.00
Melanoplus keeleri	0.00	0.00	0.19

[a] 2,206, 2,650, and 518 insects collected at the bran–13.7-m, bran–27.4-m, and control sites, respectively.

Table 57–Pretreatment densities of grasshoppers and percentage of change in densities, Crighton block, 1992

Population variable	Grasshopper taxon	Bran-bait (13.7-m)[a]	Bran-bait (27.4-m)[a]	Control[a]
Pretreatment density	All grasshoppers[b]	20.90 ± 2.513 (10)a	21.73 ± 4.950 (10)a	7.38 ± 1.975 (10)b
	Bran accepting	12.14 ± 3.188 (10)a	14.11 ± 3.955 (10)a	5.47 ± 1.898 (10)b
	Bran rejecting	8.13 ± 1.974 (10)a	5.40 ± 1.595 (10)a	1.66 ± 0.505 (10)b
	Bran vulnerable[b]	0.54 ± 0.222 (10)a	0.58 ± 0.136 (10)a	0.17 ± 0.055 (10)b
	M. sanguinipes	3.35 ± 0.744 (10)a	5.91 ± 1.065 (10)a	1.86 ± 0.619 (10)b
	P. quadrimaculatum	5.42 ± 1.603 (10)a	1.31 ± 0.669 (10)a	0.77 ± 0.339 (10)a
	C. pellucida	1.55 ± 0.802 (10)a	4.80 ± 2.929 (10)a	0.61 ± 0.610 (10)b
	M. infantilis	2.46 ± 0.847 (10)a	1.13 ± 0.269 (10)a	1.34 ± 0.799 (10)a
	A. elliotti	2.15 ± 1.347 (10)a	0.25 ± 0.142 (10)a	0.06 ± 0.036 (10)b
	A. clavatus	0.36 ± 0.134 (10)a	2.39 ± 1.505 (10)a	0.16 ± 0.087 (10)b
% change (pre- to 2-d post-treatment)	All grasshoppers[b]	10.54 ± 16.769 (10)	–61.86 ± 11.686 (10)	–12.67 ± 8.755 (10)
	Bran accepting	–19.43 ± 14.537 (10)	–59.61 ± 12.739 (10)	–3.91 ± 12.515 (10)
	Bran rejecting	86.64 ± 37.023 (10)	–69.58 ± 7.461 (10)	–11.83 ± 26.342 (8)
	M. sanguinipes	–46.02 ± 8.165 (10)	–65.02 ± 8.831 (10)	30.27 ± 27.727 (10)
	P. quadrimaculatum	60.46 ± 37.286 (7)	–82.58 ± 11.067 (8)	1.83 ± 27.897 (5)
	C. pellucida	–52.55 ± 40.391 (5)	–53.04 ± 36.443 (5)	—
	M. infantilis	–27.52 ± 23.220 (8)	–27.19 ± 19.709 (10)	45.33 ± 84.989 (7)
	A. elliotti	–14.96 ± 35.432 (9)	–90.63 ± 6.457 (6)	–47.66 ± 52.339 (3)
	A. clavatus	4.64 ± 51.069 (7)	–73.68 ± 13.662 (9)	–25.81 ± 41.576 (3)
% change[c] (pre- to July 1992)	All grasshoppers[b]	–0.34 ± 13.395 (10)	–56.61 ± 9.782 (10)	–16.68 ± 5.556 (10)
	Bran accepting	–22.16 ± 13.145 (10)	–54.40 ± 10.531 (10)	–7.70 ± 9.252 (10)
	Bran rejecting	87.04 ± 51.895 (10)	–50.63 ± 8.357 (10)	–38.71 ± 9.701 (8)
	M. sanguinipes	–50.33 ± 7.986 (10)	–66.76 ± 6.723 (10)	44.55 ± 29.791 (10)
	P. quadrimaculatum	44.63 ± 30.952 (7)	–63.12 ± 18.005 (8)	–30.11 ± 10.374 (5)
	C. pellucida	–32.01 ± 31.609 (5)	–31.52 ± 33.790 (5)	—
	M. infantilis	–41.63 ± 27.271 (8)	–27.24 ± 18.315 (10)	7.86 ± 40.249 (7)
	A. elliotti	–23.20 ± 21.464 (9)	–75.13 ± 12.699 (6)	–82.55 ± 17.446 (3)
	A. clavatus	–5.46 ± 33.256 (7)	–60.02 ± 14.534 (9)	–65.15 ± 18.355 (3)

[a] Values are means ± 1 SEM with sample sizes in parentheses. Means followed by the same letter within rows are not significantly different (Kruskal–Wallis test, $P > 0.05$).

[b] Does not include late-hatching species.

[c] Change in grasshopper densities between the pretreatment and average July 1992 densities.

Table 58–Grasshopper species composition at the Wolf Coulee block on the pretreatment sample date, 17 July 1993

Species	% of total[a]		
	Swath width (m)		
	13.7	27.4	Control
Melanoplus sanguinipes	43.52	44.31	47.48
Melanoplus infantilis	16.61	13.87	14.95
Ageneotettix deorum	11.60	11.04	3.22
Camnula pellucida	5.17	6.57	9.99
Melanoplus gladstoni	4.65	6.36	3.68
Aulocara elliotti	3.50	2.75	2.75
Melanoplus femurrubrum	3.34	2.19	3.52
Melanoplus packardii	2.14	1.80	5.27
Trachyrhachys kiowa	2.04	1.42	1.82
Melanoplus bivittatus	0.89	1.98	3.80
Aeropedellus clavatus	1.10	1.25	0.81
Amphitornus coloradus	1.05	1.07	0.66
Melanoplus dawsonii	0.47	1.42	0.08
Phlibostroma quadrimaculatum	0.94	0.73	0.16
Melanoplus keeleri	0.21	0.56	0.19
Opeia obscura	0.78	0.04	0.08
Melanoplus confusus	0.31	0.39	0.27
Hypochlora alba	0.16	0.43	0.00
Metator pardalinus	0.16	0.39	0.54
Phoetaliotes nebrascensis	0.31	0.22	0.35
Encoptolophus costalis	0.31	0.13	0.08
Boopedon nubilum	0.10	0.13	0.00
Unknown Oedipodinae	0.10	0.13	0.00
Chloealtis conspersa	0.00	0.22	0.00
Mermiria bivittata	0.00	0.22	0.00
Orphulella speciosa	0.10	0.13	0.04
Hesperotettix viridis	0.10	0.09	0.00
Arphia pseudonietana	0.10	0.00	0.08
Eritettix simplex	0.05	0.04	0.00
Arphia conspersa	0.05	0.00	0.00
Chorthippus curtipennis	0.00	0.04	0.00
Circotettix rabula	0.05	0.00	0.00
Derotmema haydeni	0.05	0.00	0.00
Psoloessa delicatula	0.00	0.04	0.04
Pseudopomala brachyptera	0.00	0.04	0.00
Spharagemon equale	0.00	0.04	0.00
Spharagemon collare	0.00	0.00	0.23
Dissosteira carolina	0.00	0.00	0.12

[a] 2,206, 2,650, and 518 insects collected at the bran–13.7-m, bran–27.4-m, and control sites, respectively.

Table 59–Pretreatment densities of grasshoppers and percentage of change in densities, Wolf Coulee block, 1993

Population variable	Grasshopper taxon	Bran-bait (13.7-m)[a]	Bran-bait (27.4-m)[a]	Control[a]
Pretreatment density	All grasshoppers[b]	9.39 ± 1.969 (10)a	9.19 ± 0.922 (10)a	8.00 ± 1.367 (10)a
	Bran accepting	7.48 ± 1.431 (10)a	7.87 ± 0.802 (10)a	6.95 ± 1.137 (10)a
	Bran rejecting	0.61 ± 0.196 (10)a	0.51 ± 0.100 (10)a	0.29 ± 0.087 (10)a
	Bran vulnerable[b]	0.54 ± 0.129 (10)a	0.19 ± 0.067 (10)a	0.36 ± 0.167 (10)a
	M. sanguinipes	4.05 ± 1.160 (10)a	4.07 ± 0.502 (10)a	3.58 ± 0.571 (10)a
	M. infantilis	1.40 ± 0.202 (10)a	1.14 ± 0.231 (10)a	1.22 ± 0.622 (10)a
	A. deorum	0.94 ± 0.147 (10)a	1 ± 0.253 (10)a	0.24 ± 0.059 (10)b
% change(pre- to 2 d post-treatment	All grasshoppers[b]	–78.16 ± 5.513 (10)	–70.95 ± 7.837 (10)	–45.67 ± 6.846 (10)
	Bran accepting	–85.92 ± 2.760 (10)	–80.37 ± 4.679 (10)	–48.74 ± 7.343 (10)
	M. sanguinipes	–85.20 ± 3.806 (10)	–88.60 ± 3.522 (10)	–32.67 ± 11.510 (10)
% change[c] (pre- to July 1993)	All grasshoppers[b]	–81.01 ± 3.608 (10)	–76.28 ± 4.548 (10)	–39.14 ± 5.983 (10)
	Bran accepting	–85.73 ± 2.532 (10)	–83.28 ± 2.806 (10)	–42.98 ± 6.393 (10)
	M. sanguinipes	–85.27 ± 4.594 (10)	–89.15 ± 2.872 (10)	–19.41 ± 14.223 (10)

[a] Values are means ± 1 SEM with sample sizes in parentheses. Means followed by the same letter within rows are not significantly different (Kruskal–Wallis test, $P > 0.05$).

[b] Does not include late-hatching species.

[c] Change in grasshopper densities between the pretreatment and average July 1993 densities.

Table 60–Grasshopper species composition at the Corral Creek block on the pretreatment sample date, 18 July 1993

Species	% of total[a] Swath width (m) 13.7	27.4	Control
Melanoplus sanguinipes	54.63	56.86	58.81
Melanoplus infantilis	17.96	20.32	20.46
Melanoplus gladstoni	6.30	4.12	2.83
Ageneotettix deorum	3.80	5.78	3.59
Melanoplus packardii	4.55	2.37	2.70
Camnula pellucida	3.55	1.86	0.55
Melanoplus femurrubrum	2.85	0.81	1.04
Phoetaliotes nebrascensis	1.20	1.08	1.87
Melanoplus confusus	0.45	1.22	1.11
Phlibostroma quadrimaculatum	0.10	1.35	0.48
Trachyrhachys kiowa	0.55	0.91	1.11
Aeropedellus clavatus	0.95	0.37	1.04
Melanoplus dawsonii	0.50	0.61	0.00
Aulocara elliotti	0.75	0.41	0.21
Opeia obscura	0.20	0.37	0.00
Melanoplus bivittatus	0.40	0.20	0.28
Amphitornus coloradus	0.05	0.41	0.07
Melanoplus keeleri	0.25	0.24	2.42
Arphia pseudonietana	0.15	0.24	0.21
Eritettix simplex	0.25	0.03	0.07
Hypochlora alba	0.00	0.14	0.07
Orphulella speciosa	0.15	0.03	0.69
Psoloessa delicatula	0.10	0.07	0.07
Metator pardalinus	0.10	0.03	0.00
Hesperotettix viridis	0.00	0.07	0.00
Encoptolophus costalis	0.00	0.07	0.00
Arphia conspersa	0.05	0.00	0.07
Unknown Oedipodinae	0.05	0.00	0.00
Hadrotettix trifasciatus	0.05	0.00	0.07
Mermiria bivittata	0.00	0.03	0.07
Pseudopomala brachyptera	0.05	0.00	0.00
Spharagemon collare	0.00	0.00	0.07
Pardalophora haldemanii	0.00	0.00	0.07

[a] 1,999, 2,958, and 1447 insects collected at the bran–13.7-m, bran–27.4-m, and control sites, respectively.

Table 61–Pretreatment densities of grasshoppers and percentage of change in densities, Corral Creek block, 1993

Population variable	Grasshopper taxon	Bran-bait (13.7-m)[a]	Bran-bait (27.4-m)[a]	Control[a]
Pretreatment density	All grasshoppers[b]	10.05 ± 2.019 (10)a	11.85 ± 1.915 (10)a	7.06 ± 1.050 (10)a
	Bran accepting	8.61 ± 1.756 (10)a	10.78 ± 1.914 (10)a	6.18 ± 0.895 (10)a
	Bran rejecting	0.17 ± 0.027 (10)a	0.38 ± 0.137 (10)a	0.17 ± 0.043 (10)a
	Bran vulnerable	0.50 ± 0.214 (10)a	0.28 ± 0.081 (10)a	0.20 ± 0.058 (10)a
	M. sanguinipes	5.34 ± 1.365 (10)a	6.45 ± 1.623 (10)a	3.99 ± 0.797 (10)a
	M. infantilis	1.80 ± 0.270 (10)a	2.81 ± 0.605 (10)a	1.50 ± 0.293 (10)a
% change (pre- to 2 d post-treatment)	All grasshoppers[b]	–23.63 ± 10.092 (10)	–40.13 ± 8.487 (10)	–17.08 ± 9.087 (10)b
	Bran accepting	–38.69 ± 6.984 (10)	–47.77 ± 9.567 (10)	–24.68 ± 11.051 (10)b
	M. sanguinipes	–31.36 ± 9.793 (10)	–34.53 ± 8.801 (10)	4.48 ± 26.760 (10)a
	M. infantilis	–57.23 ± 8.920 (10)	–44.14 ± 15.134 (10)	–37.84 ± 12.598 (10)a
% change[c] (pre- to July 1993)	All grasshoppers[b]	–41.68 ± 9.232 (10)	–48.16 ± 6.788 (10)	–36.94 ± 5.213 (10)b
	Bran accepting	–50.18 ± 7.266 (10)	–52.56 ± 8.456 (10)	–41.84 ± 5.828 (10)b
	M. sanguinipes	–41.96 ± 12.926 (9)	–44.00 ± 9.438 (10)	–25.30 ± 16.272 (10)a
	M. infantilis	–59.12 ± 7.599 (9)	–55.06 ± 9.261 (10)	–37.83 ± 13.842 (10)a

[a] Values are means ± 1 SEM with sample sizes in parentheses. Means followed by the same letter within rows are not significantly different (Kruskal–Wallis test, $P > 0.05$).

[b] Does not include late-hatching species.

[c] Change in grasshopper densities between the pretreatment and average July 1993 densities.

Table 62–Comparison of integrated pest management in rangeland and agricultural systems

Variable	Agricultural systems	Rangeland systems
System characteristics		
Plants	Low diversity: often monocultures with little genetic diversity	High diversity: numerous grass, forb, sedge, shrub, and tree species
Area covered	Small to large scale	Large scale
Pest diversity	Low: generally one or few pest species dominate; densities of pests often high in monocultures	High: generally involves numerous grasshopper species
Nontarget diversity	Low: relatively few nontarget species because of low plant, structural, species, and genetic diversity	High: generally high because of high host diversity
Management tactics		
Chemical control	Important: the main control tactic used for most pests	Important: the only effective control method currently in use
Host-plant resistance	Important: considerable effort given to developing pest-resistant plants	Not important: too many plant and grasshopper species to be very useful
Biological control	Important: many pests kept in check by natural and introduced biological control agents	Maybe important: numerous species of natural enemies may have additive effects; introduced predators/parasites have not been used.
Microbial control	Important: *B. thuringiensis* used for control of many lepidopteran and coleopteran pests. Natural epizootics effective in reducing populations of some insects.	Natural epizootics are effective in wet environments; microbial insecticides have not been used successfully but much progress is being made in this area.
Cultural control	Important: trap crops, soil nutrient management, planting times often used to manage pests	Not important: generally not used for managing grasshoppers on a large scale
Forcasting and predictive models	Important: often used for predicting population outbreaks, population trends, and for management decisions	Models have been developed for describing regional trends but are not effective for predicting year-to-year population levels. HOPPER expert system is being developed.
Action thresholds	Important: economic injury levels and action thresholds often used	Important: a standard action threshold is generally used for all grasshoppers at all locations, but its biological validity is uncertain.